

Takashi Yamano · Keijiro Otsuka
Frank Place *Editors*

Emerging Development of Agriculture in East Africa

Markets, Soil, and Innovations

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Preface

In 2002, the three coeditors of this book firmly agreed that in order to deepen our understanding of African agriculture we needed carefully collected and comparable panel data of rural households across countries over extended periods. We do not mean to say that the panel data on African agriculture did not exist. In fact, the senior editor of this book participated in the “Food Security Project” of the Michigan State University, which covered many countries in sub-Saharan Africa (SSA) and conducted panel surveys in some countries. There are also other panel data sets of rural households in sub-Saharan Africa. Yet, there is no denying that systematically collected panel data designed to analyze “the process of agricultural development” over decades in SSA remain relatively rare compared with Asia.

This becomes evident, for instance, when we compare African studies with Asian studies such as Hayami and Kikuchi (2000), which analyzes dynamic technological and structural changes in the Philippines based on the careful and repeated surveys of all households in the same villages over the three decades since the early 1970s. Another example of an Asian study is Otsuka et al. (2009), which analyzes panel data of rural households in the Philippines, Thailand, Bangladesh, and India covering nearly two decades. This too is a useful study in tracing pathways out of rural poverty over time in several Asian countries. These two studies inspired our current project leading to this book.

We began a collaborative research project between the National Graduate Institute for Policy Studies (GRIPS) represented by Takashi Yamano and Keijiro Otsuka and the World Agroforestry Center represented by Frank Place in 2003. Fortunately we received generous financial support from the 21st Century Center of Excellence (COE) Program of Japan Society for the Promotion of Science from 2003 to 2007. We have chosen Kenya, Uganda, and Ethiopia as the study sites because there are signs of emerging but varying agricultural development within and among these countries. Further, as a region of high rural population density, the factors of agricultural development that emerge in these countries are likely to be relevant for other African countries in the near future.

In order to express our strong will and commitment to repeat household surveys in these countries, we decided to call our project “RePEAT” project, abbreviated for “Research on Poverty, Environment, and Agricultural Technology.” Regarding the

environment, we decided to focus on soil fertility, as it is widely considered to be a major constraint on the agricultural growth in SSA, even though there has not been a quantitative analysis of this relationship at a significant scale. Thus, we have undertaken soil sampling at the household level in our project in the three countries. We paid special attention to emerging and promising technological changes in agriculture, such as the increased use of hybrid maize seeds, both inorganic and organic fertilizers, and improved dairy cows. Extending the RePEAT survey into complementary sites, we have conducted studies of upland NERICA rice and lowland rice in Uganda, as we find that rice is a particularly promising crop in East Africa.

Although the term RePEAT does not refer to markets, we have found in the course of our research that some product markets, such as maize, milk, and banana, and some input markets, such as inorganic fertilizer, have been emerging and developing. Furthermore, we have found profound impacts of the rapidly diffusing mobile phone network on the marketing of agricultural products. Thus we have placed special focus on the analysis of the efficiency of marketing systems. In order to incorporate marketing costs into the analyses, we use spatial data now available on road quality, distance and travel time, as well as other geographical characteristics.

The purpose of this book is to provide a synthesis of our empirical studies concerned with diverse aspects of agricultural development in Kenya, Uganda, and Ethiopia, with an objective to draw useful policy implications for strategies for agricultural development and poverty reduction. We focus on the impacts of markets, soil fertility, and technology innovations on agricultural development, as we believe that these are the critical drivers for changes in African agriculture.

Having completed the 21st century COE Program successfully, we have received the financial support of the Global COE project from 2008 to 2012. So far we have been successful in “repeating” surveys for two rounds in Kenya and Ethiopia and three rounds in Uganda in a consistent and comparable manner. We are grateful for the continuous financial support of the Japan Society for the Promotion of Science and Technology.

We received large amount of useful comments from so many researchers. We are particularly grateful to Peter Hazell and Derek Byerlee who provided invaluable comments on various occasions. James Nyoro significantly contributed to data collection based on his rich empirical knowledge and survey experience. We have also received so many useful comments and encouragements from our colleagues at the GRIPS: Jonna P. Estudillo, Hideaki Goto, Yujiro Hayami, Kei Kajisa, Kaliappa Kalirajan, Yukichi Mano, Tetsushi Sonobe, and Chika Yamauchi. In addition, we received useful comments from many researchers on various occasions: Jock R. Anderson, Pranab Bardhan, Alain de Janvry, Nobuhiko Fuwa, Yoshihisa Godo, Takashi Kurosaki, Tetsuji Okazaki, Gustav Ranis, Takeshi Sakurai Yasuyuki Sawada, and John Strauss. We would like to thank Mayuko Tanaka who provided excellent editorial support and Paul Kandasamy who carefully edited the whole manuscript.

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Part I

Introduction

Chapter 1

Purpose, Scope, and Methodology

Takashi Yamano, Keijiro Otsuka, and Frank Place

Abstract In this book, we examine hypotheses concerning the importance of markets, innovations, and soil fertility for stimulating agricultural productivity and reducing rural poverty by using large-scale household panel data, which are enriched with detailed market access and soil fertility data, from Kenya, Uganda, and Ethiopia. This chapter first presents descriptive data showing some similarities as well as differences between the three countries. A conceptual model is then described from which the main hypotheses are generated. The first hypothesis and corresponding set of case studies investigate the roles of agricultural input and output markets in agricultural development in East Africa. The second hypothesis shifts the focus of the research to the emergence and role of technological innovations in enhancing productivity and incomes. The final hypothesis tested by case studies is the importance of soil fertility in capitalizing on improved markets and innovations to increase agricultural productivity. The chapter concludes by describing the data used in the case studies and an overview of the case study chapters in the book.

Keywords Agricultural development • Market access • Agricultural technology • Soil fertility • East Africa

1.1 Introduction

Household poverty is a consequence of low endowment of human, social, natural, physical, and financial assets as well as the low returns to such assets. In order to reduce poverty, asset holdings need to increase by means of investments, but such

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investments are unlikely to occur unless the returns to assets are enhanced. Among rural households in East Africa, it appears that returns to investments in productive assets, particularly land and labor, have remained generally low because of the riskiness and limitations of smallholder agriculture due to climate uncertainty, small land holdings, and often degraded soil conditions; poor market access that keeps the ratio of input to output prices high; and lack of available technological innovations that could increase the returns to current land and labor investment. The unfavorable input/output price ratios have inhibited the use of inorganic fertilizer, resulting in widespread soil nutrient depletion in the region. In turn, the low prices and high risks of farming have created disincentives for farmers to adopt technological innovations and all of these factors have combined to perpetuate rural poverty.

In recent years, however, there has been some evidence of improvements in adoption of agricultural technologies in East Africa. For example, improved seeds and breeds, horticultural crop production, soil conservation investments, and fertilizer have been adopted in some farming areas. The region is an ideal setting for a study of the uptake and impacts of agricultural innovations. The main reason is the rich variation in national policy environments and demographic, market, institutional, topographic, and climatic factors, which offers a unique testing ground to analyze the drivers of adoption of agricultural innovations and their impacts. Further, the effects of recent policy reforms, e.g., fertilizer market liberalization in Kenya, and advances in market supporting investment (e.g., in roads and telecommunications) in all three countries, can be assessed by the multi-country study.

The majority of people in Ethiopia, Kenya, and Uganda reside in rural areas. Poverty rates are higher in the rural areas of the three countries (ranging from 42% to 53% in the three countries) than in urban areas and, therefore, the number of poor in rural areas is significantly greater than that in urban areas.¹ Agriculture is important in all three countries, accounting for the majority of total employment. In terms of income, agriculture is more important to Ethiopia's economy (43% of GDP) than in Kenya or Uganda (21–22%) due to slower development of industry and services in the former. The more robust nonfarm economies of Kenya and Uganda also translate to higher per capita incomes in those countries (\$770 in Kenya and \$420 in Uganda in 2008) as compared to a low \$280 in Ethiopia. This will affect the demand for agricultural products from domestic production and influence the types of commodities produced, the quantity and quality of commodity as well as the price that prevails. On the supply side, a key determinant is the amount of arable land available to farmers. The three countries range between 468 and 536 persons per square kilometer of arable land, leading to small average farm sizes throughout the region between 1 and 2 ha in general (Place et al. 2006). Given the importance of agriculture to income but with such limited farm size, the only practical way to increase production and incomes for a large number of smallholders is by intensification through innovation. Governments have established programs to assist smallholders, but historically this has been focused on export crops, such as coffee,

¹Unless otherwise noted, the statistics are from IFAD, www.ruralpovertyportal.org

where parastatals were created to facilitate the adoption of good varieties and use of credit for inputs. Overall, government involvement in agriculture has had a mixed record, with concerns arising about interference with the development of the private sector. Interesting cases from a political economy perspective are related to maize marketing in Kenya and fertilizer supply in all three countries, topics that are discussed in later chapters.

Smallholder agriculture is almost entirely dependent on rainfall in each of the countries, as the percentage of irrigated cropland does not exceed 3% in the region. Rainfall patterns vary considerably within each country ranging from bimodal humid highlands receiving rainfall in excess of 1,800 mm/year, to unimodal semi-arid areas with annual rainfall of below 600 mm. In the more productive subhumid and humid zones, the major staple foods will be produced, along with a host of other commodities. The main staple food is different in the three countries, with maize in Kenya, plantain in Uganda, and teff in Ethiopia. However, two commonalities are that maize is widely produced in all three countries and the area under rice cultivation is growing rapidly (near doubling in all three countries between 1998 and 2008). Productivity of major food crops has not increased significantly in recent decades. For example, in Kenya, maize production per hectare ranged from 1.4 to 1.7 tons between 1998 and 2008 and Uganda's maize yield was stable at around 1.5 tons/ha. Maize yields in Ethiopia have increased more visibly due in part to increased fertilizer use, which is concentrated on marketed crops like maize. However, aggregate fertilizer use remains low in Ethiopia and in Uganda (at less than 3 kg of nitrogen per ha in 2005) while it is (and historically has been) higher in Kenya at around 18 kg of nitrogen per ha.

Milk production is very important in both Kenya and Ethiopia where it ranks first and second, respectively, in terms of value of production among all agricultural commodities. A key factor in its importance is its wide consumption even in rural areas (for drinking tea in Kenya and for producing ghee in Ethiopia). Ethiopia's milk production comes mainly from a large number of low producing indigenous cattle, while Kenya's comes mainly from more productive improved dairy cows on more than 2 million smallholder dairy farms (SDP 2006). The different farming system patterns and trends across the region imply that the identification of promising innovations may be challenging; yet, on the other hand, in taking on this complexity, the conclusions of the study are more representative of the region as a whole and relevant to policy makers.

This book is the first systematic and rigorous empirical study of agricultural innovations on a regional scale in Africa. All of the case studies included in the book use household-level panel data, most of which are collected by Research on Poverty, Environment, and Agricultural Technology (RePEAT) project in Ethiopia, Kenya, and Uganda. The RePEAT project has interviewed more than 2,300 rural households twice in the three countries between 2003 and 2007 and asked detailed questions about household composition, assets, land holdings and quality, agricultural production, access to credit and services, and marketing. Soil samples were taken from farms and other contextual variables, for example, related to market access and climate, were created or drawn from spatial datasets.

There are at least three distinguished methodological features that differentiate this book from other books on closely related subjects. First, 9 out of the 11 case studies use panel data, and five out of the nine case studies that use panel data identify causal impacts, which are essential for generating precise policy and investment recommendations. Second, by taking advantage of the fact that the survey data are comparable across countries, four case studies attempt cross-country comparisons and are thereby able to examine the regional relevance of the findings. Third, eight case studies in this book merge household data with the detailed market access and soil fertility data, enriching the scope and depth of the analyses undertaken. In short, this book attempts to develop and synthesize findings that are representative of much of East Africa with a view to drawing policy implications for the sustainable development of agriculture in the region.

1.2 Market Access, Technological Innovations, and Soil Fertility in East Africa

In this book, we describe the recent agricultural developments in East Africa and examine the associations and causal impacts of key factors affecting farmers' behavior regarding input applications and production decisions, including technology adoption. In Fig. 1.1, the farmers' production decision is focus of the conceptual model. In the technical sense, outputs are the result of an interaction among soil quality, technology, and inputs, which are depicted in a triangle. There are many types of variables that influence the production decisions and outcomes, such as climate, and where applicable, these are accounted for in the analyses. However, some of these are omitted in Fig. 1.1 to better see the relationships studied in the

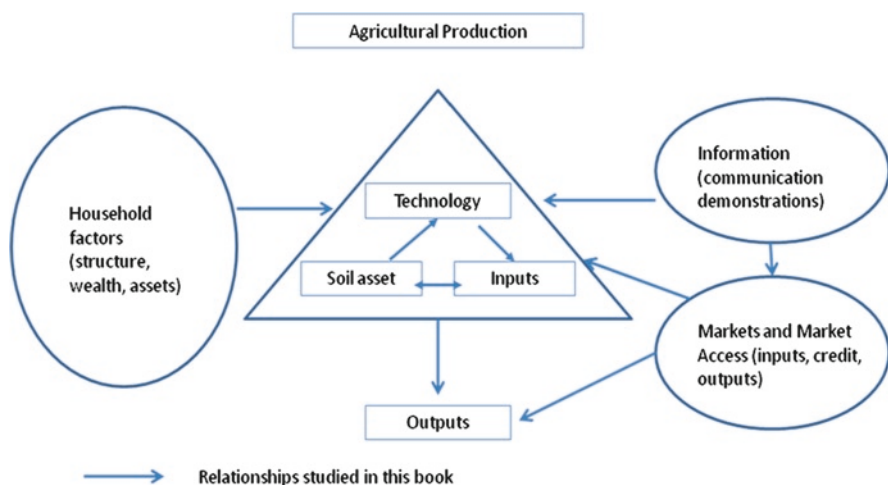


Fig. 1.1 Conceptual framework of the book

book. One set of variables that influencing the production triangle are household variables such as household composition, education, farm size, assets, and overall wealth. These factors are included in econometric analyses of uptake of technology and participation in markets. Of particular importance is to examine whether agricultural innovations are being adopted by only certain types of households.

Other important influences on production relate to investments in information dissemination and market access. Access to credit, input and output markets are analyzed in this book. Among the analyses conducted include the relationship between access to credit and use of inputs, access to improved inputs and productivity, and access to output markets and income generated. Information dissemination can enable farmers to be more aware of production or market opportunities and we also examine these relationships as well. The following sections use the model to develop key hypotheses that guide the analyses in the book.

1.2.1 Market Access

Market access, which is shown in Fig. 1.1, is considered poor in Sub-Saharan Africa (SSA). Rural roads are generally inadequate in terms of both coverage and quality, resulting in high transportation costs in the region (Calderón and Servén 2008). The poor market access increases input costs and reduces the selling prices of farm products and, hence, discourages farmers from participating in markets (de Janvry et al. 1991). To be more specific, the high transportation costs increase inorganic fertilizer prices (Gregory and Bumb 2006), discourage farmers from producing perishable and high-value crops (Goetz 1992; Jayne 1994; Jacoby 2000), and, hence, prevent them from increasing farm income. A recent study by Stifel and Minten (2008) examines the relationship between isolation and agricultural productivity in Madagascar. They find that the crop yields of the three major crops in Madagascar, i.e., rice, maize, and cassava, are lower in isolated areas than in non-isolated areas.

Market integration has been a major concern in SSA, especially for some landlocked African countries where markets are not well integrated with those in neighboring countries. Indeed, previous studies find that landlocked countries are more vulnerable to domestic production shocks and experience large price volatilities (Byerlee et al. 2006). Because poor people, including the urban poor, spend a large share of their total expenditure on food, they would benefit from reduced prices and price volatilities due to market integration. Indeed, linkages to marketing centers have been found to contribute to rural households' attempts to escape from poverty (Krishana 2004; Minot 2007).

To integrate markets and let the markets, instead of government agencies, offer signals to allocate resources, structural adjustment programs were implemented in the 1980s and 1990s in many countries in SSA. To examine the impacts of the structural adjustment programs on market integration, many studies have tested the market integration internationally and domestically by using time series data. Some studies find improved market integration after liberalization (Badiane and Shively 1998), while

others find markets remain poorly integrated even after the introduction of the structural programs (Lutz et al. 2006; Negassa et al. 2004; Fafchamps 2004; Poulton et al. 1998). These studies, however, only examine market integration of price variability across different markets. However, even if markets are well integrated across space, local farmers would not benefit from the market integration if farm villages are not integrated with the markets. Thus, there is a need for further studies on this issue.

Although farmers in SSA have been poorly informed about market prices in the past, a dramatic change in the use of information technology is taking place across African markets (Donner 2004; ITU 2007). Indeed, mobile phone networks have been expanding rapidly in many countries, where the average number of mobile phone units per 100 inhabitants reached 9.1 in 2004, with an annual growth rate from 1999 to 2004 of 59.7%. Improved information technology is expected to reduce transportation costs, which include search and marketing costs. Jensen (2007), for instance, identifies the impact of the introduction of mobile phones on marketing in India. He shows that fishermen increase arbitrage among local fish markets after the introduction of mobile phones, leading to a decline in the variation in fish prices and a reduction in spoilage. In Niger, Aker (2008) carefully compiles secondary market price data on grains across 42 domestic and cross-border markets and finds that the use of mobile phones reduces grain price dispersion across markets by a minimum of 6.4% and reduces intra-annual price variation by 12%. It is not well understood, however, how much subsistence African farmers benefit from the improved mobile phone coverage.

The preceding discussion demonstrates that market access can affect overall agricultural development significantly in the region through a number of different channels. In East Africa, market infrastructure still remains poor both in terms of physical condition of roads, rails, storage facilities, and trading centers as well as the quality of market institutions. We find, however, some signs of improvement in market access and market institutions due, importantly, to market reform efforts. Thus, we postulate the following hypothesis about agricultural markets:

Hypothesis 1: The functioning of agricultural product and fertilizer markets in East Africa responds favorably to investments in transportation and communication and to government commitment to private market development.

This hypothesis embraces many specific hypotheses that are examined throughout the book, but is the main focus of Chaps. 2–5. The rapid development of Geographical Information Systems (GIS) methods and the increasing availability of related digitized information make it possible to test Hypothesis 1 by measuring market access by distance and driving time to the urban markets and examining how market access affects the production decisions of farmers through input and output prices. In general, the case studies in this book find evidence, which supports this hypothesis. In our view, a few decades of market reform efforts seems to have brought some positive changes in market institutions in some countries, and stable economic conditions have gradually improved the market infrastructure in the region. Although there remain further issues that need to be addressed, we provide evidence that agricultural markets are increasingly functioning to foster better resource allocation by affecting farmers' economic incentives.

1.2.2 *Agricultural Technology*

In addition to market access, the returns to the productive assets and agricultural inputs depend on agricultural technologies as we show in Fig. 1.1, forming part of an agricultural production triangle with soils and inputs. If farmers use improved and appropriate technologies suitable for their agroecological conditions, they would be able to obtain larger outputs even for the same amounts of inputs. In many African countries, there is a strong need to intensify farming systems because of the rapidly growing population and the increasingly limited availability of uncultivated land in many areas. Yet, cereal production per hectare has been largely stagnant in the region, in contrast to Asia where the Green Revolution has significantly contributed to the improvement of the cereal crop yields for the last several decades. The most important lesson for SSA to learn from Asia's Green Revolution is that the increased application of fertilizer and the development and wide adoption of improved high-yielding varieties are essential components for increasing crop yields at national scale (David and Otsuka 1994; Otsuka and Yamano 2005a).

Fertilizer use in the region has remained at a low level for many decades, and the low fertilizer use partly explains the lagging agricultural productivity growth in the region (Morris et al. 2007). For instance, while average fertilizer use has increased from 38 kg/ha in 1982 to 101 kg/ha in 2002 in South Asia, it increased only from 7 to 8 kg/ha during the same period in SSA. Thus, to achieve a substantial increase in agricultural productivity, experts and policy makers agree on the urgent need to increase the inorganic fertilizer use in the region, although they may not agree on how to address the need.

One way of increasing inorganic fertilizer use is to subsidize it. In the 1970s and early 1980s, many African countries adopted state-led fertilizer distribution policies where governments were heavily involved in fertilizer supply schemes via public agencies. During this period, fertilizer use increased significantly, along with the increased adoption of improved seeds, thereby raising hopes for some countries to follow the Asian Green Revolution model (Eicher 1995; Byerlee and Eicher 1997). However, because of the heavy financial burdens to support state-led policies, many public agencies accumulated massive debts. As a result, during the following structural adjustment period in the late 1980s and 1990s, many governments adopted market reform policies, although the degree of how thoroughly they have implemented them depends on the countries (Jayne et al. 2002). The results of the market reform policies are mixed and controversial, and the number of African countries that have readopted the state-led approach has been increasing in recent years. Studies of the effects of the Malawi fertilizer subsidy program indicate that there have been positive outcomes on food production and overall benefit cost ratio, but the program is costly, thereby squeezing out other possible investments (Dorward and Chirwa 2009).

Although the fertilizer subsidy approach assumes that the main constraint on farmers' fertilizer use is the credit constraint, there are other competing hypotheses (Morris et al. 2007; Kelly 2006). A market-based hypothesis suggests that farmers are responding to the high fertilizer price, which has been the result of high

transportation and marketing costs in Africa (Jayne et al. 2003a; Gregory and Bumb 2006). As a result, farmers in East African countries are discouraged from applying inorganic fertilizer on maize and other staple farm products. A third, a nonmarket-based hypothesis emphasizes farmers' lack of knowledge on the impacts of inorganic fertilizer and high-yielding varieties (surveyed in Morris et al. 2007). The lack-of-knowledge argument is less suitable in some African countries where many farmers have used inorganic fertilizer before, especially when it was heavily subsidized prior to the structural adjustment period. However, it is still applicable in some countries, such as Uganda, where many farmers have not used inorganic fertilizer. Thus, there is also a need to identify the real constraints on inorganic fertilizer use in different places as the particular context matters greatly.

Because of the high price of inorganic fertilizer, it is natural for farmers and policy makers to turn their attention to alternative agricultural technologies that use less inorganic fertilizer. The particular technology that we focus on in this book is a mixed system of intensive dairy and crop farming, which is adopted by some farmers in the East African highlands (Otsuka and Yamano 2005b). This farming system is based on the use of organic fertilizer generated from the manure and urine of improved dairy cattle, i.e., crossbreeds of European and local cattle, which are often raised in stalls. It is much easier for farmers to feed and milk dairy cows in stalls, and at the same time, it makes it easier for them to collect manure and urine from the stalls, where the improved cattle are usually kept.

The need for organic fertilizer application is acute in the region where land degradation is a serious concern and soil organic matter is depleted (Smaling et al. 1997; Koning and Smaling 2005; Pender et al. 2006). Long-term experimental studies show that continuous cultivation with low nutrient inputs decreases soil fertility and crop yields. A combination of inorganic and organic fertilizers is necessary to sustain and improve crop production on depleted soils (Bationo et al. 1998; Bekunda et al. 1997). Where organic manures are generated internally within a farming system, the total amount of soil nutrients available for crops may not increase within the system unless there is deep capture and recycling from trees or from biological nitrogen fixation (Buresh 1999). Soil scientists also show that the nitrogen use efficiency could be improved significantly by improving soil management at various steps starting from livestock feeding to crop harvesting (Rufino et al. 2006). This is another area where evaluation studies are needed.

Rice is not usually considered an important staple crop in East Africa, but the consumption of rice has been increasing far more rapidly than its production in the region due to rapid population growth and urbanization (Africa Rice Center 2008). Given that rice can be a major cereal crop, which has great potential for increasing its productivity in SSA, strategic efforts to enhance rice production are urgently needed not only for food security but also for income generation (Otsuka and Kijima 2010).

One recent promising innovation in rice research is New Rice for Africa (NERICA), which is a set of high-yielding upland rice varieties suited to the African environment obtained by crossing rice varieties of Asian origin from the species *Oriza sativa* with varieties of African origin from the species *O. glaberrima*. The resulting traits have been considered by many to offer significant opportunities for

productivity increases and poverty reduction in Africa (Jones et al. 1997). However, studies of the impacts of NERICA in smallholder agriculture have been limited. The potential for lowland rice is also large in SSA where there are untapped irrigation opportunities and wet lands that are used only during the dry season by farmers. Because upland and lowland rice cultivation is still new to many African rice farmers, it seems that basic knowledge transfers can increase its productivity significantly.

Despite the overall low agricultural productivity in East Africa, there seem to exist promising technologies that could be adopted by farmers to increase their productivities significantly. Recent developments in agricultural markets can help farmers acquire such technologies and provide necessary inputs at reasonable prices in a timely fashion. Thus, in this book, we postulate the following second hypothesis:

Hypothesis 2: Farmers respond to improved market conditions by applying more fertilizer, adopting more productive cows and high-yielding crop varieties, and earning more profits from crops.

Chapters 3–7 examine this hypothesis. Since farmers choose technologies that are suitable to their ability and conditions, evaluating returns to adopted technologies is complicated because of the self-selection problems. Some case studies in this book address this issue by analyzing household panel data.

1.2.3 Soil Fertility

For rural households in East Africa, land is one of the most important assets because most rural households rely heavily on farm income (Jayne et al. 2003b). The amount of arable land available per farmer, however, has declined by almost half from 0.7 ha per person in the 1990s to 0.4 ha per person in the 2000s in the region (FAO 2008). As previously discussed, the quality of the land is also considered to be deteriorating because of continuous cultivation with little external fertilizer application and inadequate soil management (Smaling et al. 1997; Nkonya et al. 2004; Nkonya et al. 2008).

Land degradation decreases the returns to land in at least three ways. First, it decreases the option of choosing crops that can be profitably cultivated on a farm. Farmers working on poor soils are forced to cultivate crops that can grow well even on such soils, such as cassava and other root crops. Second, land degradation decreases the yield of a given crop. Third, declining soil fertility may decrease the returns to external fertilizer (Marennya and Barrett 2009). Because of these three pathways, we expect that farm households with poor soils have lower crop productivity and income than farm households with fertile soils, after controlling for the land size and other factors.

A major problem with previous studies on soil fertility is that they analyze few samples from a small area. This is because soil sampling and testing are expensive and time consuming. For this book, as we will explain later, we collected soil samples from a large number of households who live in Ethiopia, Kenya, and

Uganda and analyzed soil samples with a new and inexpensive method called near-infrared reflectance spectroscopy (NIRS) at the same soil laboratory at the World Agro-forestry Center. Because the soil samples are analyzed by the same method and laboratory, we are ensured that the soil data are comparable across countries. Thus, by using the same soil data, we test the following hypothesis:

Hypothesis 3: Poor soil fertility impedes the adoption of fertilizer responsive crop varieties and the use of inorganic fertilizer, even though it may increase the use of organic manure to restore the soil fertility.

Chapters 3 and 7–11 test this hypothesis. Because we have comparable soil fertility data from three countries, some of these case studies conduct cross-country analyses and examine the degree to which soil fertility explains the differences in agricultural productivity across sites and countries. Few previous studies have conducted such analyses because comparable soil fertility data were not available. This is also an important contribution of this book.

1.3 Panel Surveys Used in This Book

In this book, we primarily use household and community panel data collected in Ethiopia, Kenya, and Uganda (Table 1.1 and Fig. 1.2). As mentioned before, the surveys were conducted as part of a project called the Research on Poverty, Environment, and Agricultural Technology (RePEAT). The RePEAT project used stratified random samplings of communities in the target regions and aimed to randomly select 10 households per selected community.

In August to October of 2003, the first RePEAT survey was conducted in Uganda jointly by Foundation for Advanced Studies on International Development (FASID), National Graduate Institute for Policy Studies (GRIPS), and Makerere University. The survey covered 94 Local Council 1s (LC1s) and 940 households in the country,

Table 1.1 Panel data used in case studies in this book

Country	Survey year	Number of communities	Number of households	Regions covered
Ethiopia	2004	40	420	Central to southern regions
	2007	40	400	
Kenya	2004	99	934	Central and western regions in both years, eastern only in 2004 only
	2007	76	725	
Uganda	2003	94	940	All regions, except north region
	2005	94	894	
Uganda:				
NERICA survey	2004	10	400	Western Uganda
Lowland rice	2009	4	300	Eastern Uganda

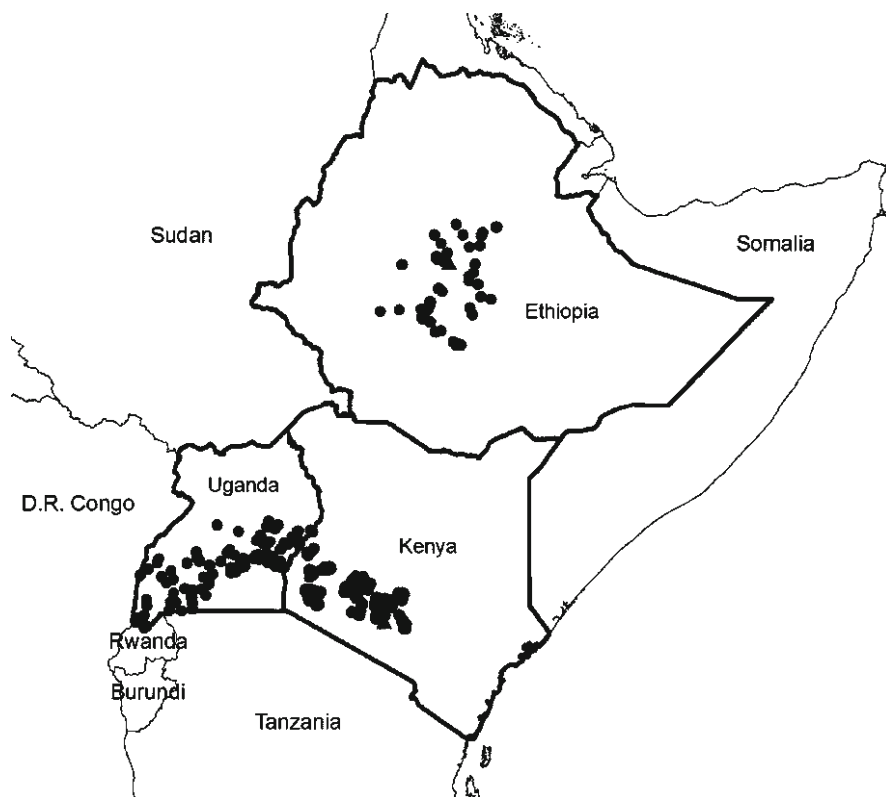


Fig. 1.2 Map of sample communities in East Africa

but excluded the north regions because of security concerns in those regions. The sample for the RePEAT survey largely builds upon and complements a completed research project on policies for improved land management in Uganda, conducted by the International Food Policy Institute (IFPRI) and Makerere University between 1999 and 2001 (Pender et al. 2001). In 2005, the second RePEAT survey was conducted targeting the 940 households who were interviewed in 2003, and 894 households were successfully re-interviewed. The attrition rate was about 4.8%.

The Kenya RePEAT surveys were conducted in 2004 and 2007 jointly by GRIPS, the World Agroforestry Center, and Tegemeo Institute of Agricultural Policy and Development. Prior to the RePEAT surveys, the Smallholder Dairy Project (SDP)² had already collected data from over 3,300 rural households in the

²The SDP project is a collaborative research project jointly by the Ministry of Livestock Development and Fisheries, the Kenya Agricultural Research Institute, and the International Livestock Research Institute (ILRI).

Central, Rift Valley, Nyanza, and Western provinces, including some sub-locations in Eastern Province, which are of higher potential near Mt. Kenya. The SDP project selected households according to a random sampling procedure that uses transects connecting randomly selected landmarks in each sample community to identify households (Staal et al. 2001). For the 2004 RePEAT survey, 99 sub-locations (the smallest administrative unit in Kenya) were randomly selected from sub-locations where the SDP households resided, and 10 SDP households were randomly selected for reinterviews from each sub-location. Ultimately, 934 households were interviewed in the 99 sub-locations in 2004. In 2007, the second RePEAT survey was conducted, but the targeted sub-locations were reduced from 99 sub-locations to 76 sub-locations, excluding all sample sub-locations in Eastern Province and some in Central Province, because of a budgetary shortage. Out of 777 target households in the 76 sub-locations, the project interviewed 725 households (the attrition rate is 6.7%).

Finally, the Ethiopian surveys were conducted in 2004 and 2007 by FASID, GRIPS, the International Livestock Research Institute (ILRI), and Ethiopian Development Research Institute (EDRI). The Ethiopian survey covered 40 Peasant Associations and 420 households in the central and southern regions, excluding the northern and eastern regions, which are relatively poor. Thus, the Ethiopia data set covers the better regions of the country and the income figures in this study would overestimate the national average. Because the RePEAT surveys were coordinated under the same project, the questionnaires employed are almost identical, especially for the core components including income and expenditure modules, thus allowing for meaningful comparisons across the three countries. All the surveys were conducted in rural areas.

Soil samples were collected from sample households during the first round of the RePEAT surveys in the three countries. We took soil samples from the largest plot where the sample households cultivated cereal crops. The soil samples were sent to the soil laboratory at the World Agroforestry Center (ICRAF) in Nairobi and were analyzed by a new method called near-infrared reflectance spectroscopy (NIRS), following protocols developed by Shepherd and Walsh (2002) and Cozzolino and Morton (2003). Many of the case studies in this book use soil carbon content as the main indicator of soil fertility. The soil carbon content is a good proxy for soil organic matter (SOM), which is derived from the decayed tissues of plants and animals and from animal excreta (Ngugi et al. 1990). Although SOM may not represent the most important aspect of soil fertility, its status is often taken as a strong indicator of soil fertility and land degradation because it is now recognized that SOM tightly controls many soil properties and major biogeochemical cycles.

To measure market access, the case studies in this book employ several indicators such as distance or driving time to markets. We measure the distances from each sample household to markets by using the geographic information system (GIS) coordinates of each sample household and markets. By using digitized road maps, four road types are identified and assigned an average driving speed on each road type, allowing us to compute the driving time from each sample household to each

market. The case studies that use driving time and other market access indexes have detailed explanations on how they calculate the driving time. Because all of the case studies use similar methods of measuring market access, it is possible to compare the results across studies.

1.4 Scope of the Book

Part II of this book investigates the roles of agricultural input and output markets in agricultural development in East Africa. While markets are necessary for innovations to take place, it is widely believed that agricultural markets do not work well in SSA. The purpose of Part II is to examine the validity of this dominant view of agricultural markets in light of our new data sets.

The first agricultural market to be analyzed in this book is the maize markets in Kenya and Uganda. To increase returns to agricultural production, farming villages need to be integrated with local markets. To examine how villages are integrated with local markets, Yamano and Arai (Chap. 2) analyze the farm-market price spreads of maize in Kenya and Uganda. The farm-market price spread is the difference between the market price of maize at the nearest maize market, where monthly market data are available, and the farm-gate price that each maize farmer who sold maize received. The authors examine the relationship between the farm-market price spread and driving time from each sample household to the nearest maize market and find that the price spread is about 15% and 33% of the market price in Kenya and Uganda, respectively. In both countries, the price spread increases by 2% points for each additional 1 h driving hour away from the nearest maize market.

The same authors turn their attention to an input market in the next chapter (Yamano and Arai, Chap. 3). They investigate the determinants of inorganic fertilizer use on major cereal crops in East Africa. The fertilizer policies in the three countries are very different: Kenya is one of a few African countries that have thoroughly and successfully implemented fertilizer market reform policies; the Ethiopian government, on the other hand, reversed its market reform policy and has been heavily involved in fertilizer credit programs in recent years; finally, in Uganda, although the government does not intervene strongly, the fertilizer market has never expanded to a significant level. By using the panel data in these three countries, the authors estimate the determinants of the fertilizer price and application at the household level and evaluate the fertilizer policies in each country to draw lessons for African countries in general and these East African countries in particular.

Regarding the fertilizer credit program in Ethiopia, Matsumoto and Yamano (Chap. 4) conduct a rigorous evaluation by using panel data and find that the provision of credit increases inorganic fertilizer application by 35 kg/ha. The authors, however, find that only about 10% of the sampled farmers cultivate high-yielding maize or wheat varieties, while others apply the inorganic fertilizer on local varieties of maize and wheat. As a result, they find only limited impacts on crop yields,

suggesting that the limited impacts are due importantly to low adoption rates of high-yielding varieties, which should accompany the inorganic fertilizer use.

Dairy production has become a very important income source, which is relatively stable compared with crop production. In the next chapter, Kijima, Baltenweck, and Yamano (Chap. 5) study the case of the milk industry in Kenya, where private traders have gradually entered the marketing business since the milk market liberalization, and examine the effects of the change in the market structure on the farm-market price spread of milk over time. According to their estimation results of the panel data, the authors find a decline in the farm-market price spread of milk over time. They argue that the decline in the price spread is due to the development of marketing institutions, which include experience gained by private traders who entered the market after the liberalization. The next chapter, Baltenweck, Yamano, and Staal (Chap. 6), investigates the dynamics in dairy production in the period following the liberalization. The objective of this chapter is to identify opportunities for dairy growth and constraints to its development since dairy has been identified as a key pathway out of poverty for smallholder households in the country.

Market access and activity do not depend solely on the physical distance to the market. A remarkable change that has been taking place is the increased use of information technology across African markets. Muto and Yamano (Chap. 7), therefore, assess the impact of mobile phone network expansion on farmers' market participation in Uganda. During the 2-year period between the first survey in 2003 and the second survey in 2005 in Uganda, the authors find that the mobile phone network expanded from 41 to 87 communities out of the 97 RePEAT communities in the country and that the mobile phone network expansion had a large impact on the marketing of banana, which is a highly perishable product in remote areas, while they did not find any significant impact on the marketing of maize, which is a storable product.

Part III of this book shifts the focus of the research to the role of soil fertility and emerging technological innovations. One of the arguments for the low application of the inorganic fertilizer in East Africa is that returns to fertilizer application are low because of degraded soils which have low capacity to hold external soil nutrients (Marennya and Barrett 2009). Another argument is that fertilizer prices are prohibitively high in SSA. However, no study has attempted to test these competing hypotheses simultaneously. Matsumoto and Yamano (Chap. 8), therefore, examine this issue by using 2-year panel data of maize production on nearly 4,500 plots in Kenya and Uganda, for which they have laboratory-measured soil fertility data. In particular, the authors estimate the direct impact of the level of soil fertility on the maize yield and examine if the improved soil fertility increases the returns to the application of inorganic and organic fertilizers. The results of the analyses indicate that the Kenyan maize farmers have applied inorganic fertilizer roughly at the economically optimal level on both purchased high yielding variety (HYV) and local/recycled HYV maize. In Uganda, even the low application of inorganic fertilizer is not profitable because of the unfavorable relative price of fertilizer. The authors do not find any evidence to support the hypothesis that marginal returns to the external fertilizers increase with the improvement of the soil fertility.

Yamano (Chap. 9) examines a dairy–banana integration farming system in Uganda, which relies on manure taken from dairy production instead of on inorganic fertilizer. The author finds that the use of organic manure has a significant effect on soil fertility, which, in turn, has a strong positive impact on banana yields. In our view, the active use of manure in areas of SSA where fertilizer is expensive and improved dairy cows are widely adopted, such as the central highlands of Kenya, is one promising avenue toward the intensification of farming systems.

The next two chapters focus on rice, which, as previously mentioned, is rapidly becoming an important staple crop in many East African countries. Kijima, Otsuka, and Sserunkuuma (Chap. 10) turn their attention to upland rice production in Uganda where a new upland rice variety, called New Rice for Africa (NERICA), has been recently introduced. NERICA is drought resistant, early maturing, and high yielding, and hence suitable to upland cultivation in SSA. The authors confirm its significant impacts on rice yield, farm income, and poverty reduction, which is reminiscent of the Asian Green Revolution. One of the reasons why yields in lowland rice are currently far lower than their potential in SSA is that many rice growers cultivate lowland rice without applying appropriate cultivation practices. Thus, Kijima, Ito, and Otsuka (Chap. 11) evaluate the impacts of demonstrations or training based on improved rice technology on its diffusion and rice yields by using the case of the JICA (Japan International Cooperation Agency) program.

Finally, the last part of the book, Part IV, has two concluding chapters. In the first chapter of this part, Yamano and Kijima (Chap. 12) identify the associations of soil fertility, agricultural technology, and market access with per capita income and various income sources in Ethiopia, Kenya, and Uganda. They use panel data matched with soil fertility and market access data and find that both soil fertility and market access affect household welfare significantly.

Based on the findings from the case studies, we draw policy implications and conclusions in Chap. 13. The critical findings in Part II are that markets for fertilizer and some agricultural products are functioning and that farmers are responding to changes in the markets by changing crop choice, input use, and agricultural technologies. Furthermore, such choices are found to be critical determinants of income and the extent of poverty. Thus, there is overwhelming evidence for governments to prioritize investments in improving transport systems and information networks to transform the agricultural sectors in East Africa. The case studies in Part III suggest that there are ample opportunities for major technological innovations that are potentially suitable for local conditions, e.g., hybrid maize, NERICA rice, improved varieties of lowland rice, and the dairy–crop mixed farming system. In order to realize this potential, however, improving soil fertility is found to be a prerequisite. Thus, we recommend the search for the optimum mix of organic and inorganic fertilizer use with farming systems that fit best in local conditions in East Africa. Policymakers need to understand the recent market developments and the possibilities of technological innovations so as to implement policies that would nurture such developments and innovations in the coming years.

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Part II

Market Access and Innovations

Chapter 2

The Maize Farm-Market Price Spread in Kenya and Uganda

Takashi Yamano and Ayumi Arai

Abstract In this chapter, we analyze the farm-market price spreads of maize in Kenya and Uganda to examine how agricultural sectors are integrated with local markets. The farm-market price spread is calculated by subtracting the farm-gate price from the market price at the nearest maize market. We find that the farm-market price spread of maize is about 15% and 33% of the market price in Kenya and Uganda, respectively. In both countries, the price spread increases by 2% points for each additional driving hour away from the nearest maize market. While the former finding suggests that the overall marketing costs are lower in Kenya than in Uganda, the latter finding indicates that reductions in transportation costs will increase the farmer prices of maize in both countries.

Keywords Price spread • Market • Maize • Kenya • Uganda

2.1 Introduction

A well-integrated market system is considered to be necessary not only for the efficient allocation of productive resources but also for a reduction in price risks by preventing unnecessary price volatility. In developing countries where local markets are fragmented, a localized crop scarcity can lead to famine in the area (Ravallion 1986). The lack of market integration has been a major concern for countries in Sub-Saharan Africa (SSA) where domestic markets are sparsely

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located due to low population densities and are isolated from international markets if the countries are landlocked. Indeed, previous studies find that landlocked countries are vulnerable to domestic production shocks and experience large price volatilities (Byerlee et al. 2006). Because poor people, including the urban poor, spend a large share of their total expenditure on food crops, they would benefit from reduced price volatilities due to market integration. Thus, linkages to marketing centers have been found to contribute to rural households' efforts to escape from poverty (Krishana 2004; Minot 2007).

To integrate markets and enable the markets, not government agencies, allocate resources, structural adjustment programs were implemented in the 1980s and 1990s in many countries in SSA. To examine the impacts of the structural adjustment programs on market integration, there have been many studies that have tested market integration internationally and domestically by using time series data. Some studies find improved market integration after the liberalization (Badiane and Shively 1998), while others find that markets remain poorly integrated even after the introduction of the structural programs (Lutz et al. 2006; Negassa et al. 2004; Fafchamps 2004; Poulton et al. 1998). In Africa, particularly, there are some studies that examined market integration of cereal crops, such as maize (Faminow and Laubscher 1991; Campenhout 2007; Goletti and Babu 1994; Rashid 2004). These studies, however, only examine integration from the perspective of price correlation across markets. Even if markets are well integrated across space, local farmers would not benefit from market integration if their market access is poor. Previous studies find that many small-scale farmers remain at the subsistence level, not selling their crops at markets (Jayne et al. 2006; Barrett 2008).

To examine how agricultural sectors, consisting of small-scale farmers, are integrated with local markets, we analyze the farm-market price spreads of maize in Kenya and Uganda. The farm-market price spread is calculated by subtracting the farm-gate price from the market price at the nearest maize market. Because we think transportation costs contribute to the farm-market price spread significantly, we examine the relationship between the farm-market price spread and the driving time from each sample household to the nearest maize market where we have monthly maize price data. We are able to measure the driving time from each sample household to the nearest maize market from having georeferenced each sample household and the closest major maize markets. By using digitized road maps of Kenya and Uganda, we identify four road types and assign an average driving speed on each road type. To measure the farm-market price spread, we compare the average market price in the 4 month period following harvest at the nearest market with the farm-gate maize price obtained from household surveys. In this chapter, we find that the farm-market price spread of maize is about 15% and 33% of the market price in Kenya and Uganda, respectively. In both countries, the price spread increases by 2% points for each additional driving hour away from the nearest maize market. While the former finding suggests that the overall marketing costs are lower in Kenya than in Uganda, the latter finding indicates that additional transportation cost associated with an increase in driving time affects the marketing cost equally between the two countries.

The chapter is organized as follows. [Section 2.2](#) describes the maize markets in Kenya and Uganda. [Section 2.3](#) explains the market price data and the household panel data used in this chapter and presents descriptive analyses of the farm-market price spreads. The estimation models and variables are explained in [Sect. 2.4](#), while the estimation and simulation results are discussed in [Sect. 2.5](#). Finally, we discuss policy implications in [Sect. 2.6](#).

2.2 Maize Markets in Kenya and Uganda

In 1988, during the structural adjustment period, the Kenyan government liberalized its maize market by allowing private traders to operate legally, instead of illegally as was the case before the liberalization, while keeping the National Cereals and Produce Board (NCPB) active. Before the liberalization, the NCPB was the sole agency that could procure and sell maize at administratively determined prices. Even after the liberalization, the NCPB continued to procure and sell maize at administratively determined prices, and to store maize as a contingency against future shortages. Jayne et al. (2008) find that NCPB activities have stabilized maize market prices in Kenya and raised average price levels roughly by 20% between 1995 and 2004.

According to Jayne et al. (2006), only 30% of their nationwide sample households in rural Kenya are net sellers of maize, and roughly 50% of all the maize sold is from fewer than 3% of households. Thus, the increased maize price due to the NCPB activities has benefited a small number of small-scale maize farmers who are net sellers of maize, as well as large-scale commercial maize farmers. The increased maize price, however, is like a tax imposed on urban consumers and small-scale maize farmers who are net buyers of maize. Indeed, these groups have opposed NCPB activities that raise maize prices. Thus, the Kenyan government faces a classic “food price dilemma,” where it is pressured to keep the maize price high for net maize sellers while it is pressured to do the opposite for urban consumers and net-maize-buyer farmers.

Regarding trade policy, the Kenyan government imposed various tariffs on maize imports at border crossings to support domestic maize prices until January 2009.¹ However, because the Kenya–Uganda border is wide and difficult to monitor, informal cross-border trade occurred regularly. According to the Regional

¹In 2008, after poor maize harvests and restrictions on maize imports, the maize price increased dramatically. The food crisis deepened with allegations of corruption over the issuing of import licenses and a lack of transparency over the sale of subsidized NCPB grain (Ariga et al. 2010). The allegations have led to the sacking of most of the NCPB Board of Directors and 17 senior managers. In January 2009, responding to the food crisis and allegations, the Kenyan government lifted the import duty on maize, allowing importers to buy maize from the international market. Note, however, that the analyses of this chapter use data taken in the period from 2003 to 2007 when the Kenyan government imposed import duties on maize.

Agricultural Trade Intelligence Network (RATIN)², which monitors regional agricultural commodity trade flows at selected border crossings between countries, the average amount of maize export from Uganda to Kenya was about 160,000 tons in the 3-year period of 2005–2007 (Benson et al. 2008). As a result, Kenya imported about 5% of its maize consumption from Uganda during this period. It was argued that the NCPB support price policy encouraged maize imports from Uganda at the same time that the official trade policy attempted to suppress it.

In Uganda, maize is the third most important staple crop, after plantain and cassava, in terms of caloric intake and is widely produced nationwide, especially in eastern region toward Kenya. Although the Ugandan government currently does not impose export duties on maize exports to Kenya, informal interviews with Ugandan traders suggest that the Ugandan government has prohibited maize exports at border controls after major drought seasons in the country. Like Kenya, Uganda also cannot escape from the food price dilemma.

One way to address the food price dilemma is to reduce the farm-market price spread, which measures the price gap between the farm-gate price that farmers receive and the market price that consumers pay. If the farm-market price spread is reduced, maize farmers can receive a higher farm-gate price, while keeping the market price constant. The farm-market price spread can be reduced by reducing the transportation and transaction costs of trading maize through investing in transportation infrastructure and developing competitive market institutions. In the following sections, therefore, we focus on the farm-market price spread and examine its determinants.

2.3 Price Data and Driving Hours

2.3.1 *Market Price and Household Data*

The monthly market data used in this chapter come from RATIN. RATIN has monthly maize market price data from nine major markets in Kenya, but only four markets (Mombasa, Nairobi, Eldoret, and Kisumu) have relatively adequate monthly data with fewer missing months than the other five markets. Among the four markets with adequate data, we choose three markets (i.e., Nairobi, Eldoret, and Kisumu) that are located near our sample households that live in Central and Western Kenya. In Fig. 2.1, we present the locations of the maize markets where we have monthly maize price data and the sample households. In Uganda, only Kampala has adequate monthly price data of maize in the RATIN data set. As a result, we use the RATIN monthly maize price data from four cities in Kenya and Uganda. As one can see in the figure, some households in Uganda are located closer to Kisumu than to Kampala. As mentioned earlier, RATIN data on regional trade

²RATIN data are available from <http://www.ratin.net/>

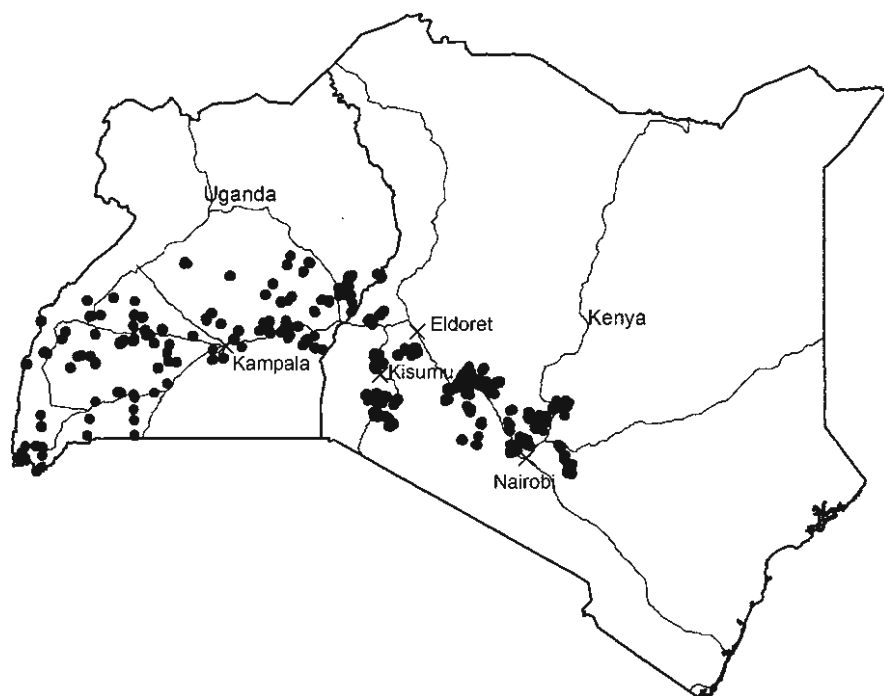


Fig. 2.1 Map of four maize markets and sample households in Kenya and Uganda

indicate significant maize exports from Uganda to Kenya. Thus, for some maize producers in Uganda, the maize market prices at Kisumu are more important than the Kampala maize price. Thus, we calculate the driving time from each household in Uganda to the two maize markets, i.e., Kampala and Kisumu, and choose the closest maize market for each household. Later in this section, we explain in detail how we select the nearest market for each household and calculate the driving time.

The household data used in this chapter come from household-level panel surveys in Kenya and Uganda, collected as part of the Research on Poverty and Environment and Agricultural Technology (RePEAT) Project. All surveys employ comparable questionnaires across countries and time. In addition, soil samples were collected from maize fields when the first rounds of the surveys were conducted. The surveys in Kenya were conducted in 2004 and 2007. The first round of the surveys covered 899 randomly selected households located in 100 sub-locations scattered in the central and western regions of Kenya.³ In the second round, seven sub-locations in Eastern province were dropped because of the scale reduction of

³These two waves of surveys in Kenya were conducted by Tegemeo Institute, with financial and technical help from National Graduate Institute for Policy Studies (GRIPS).

the survey project. Thus, in this chapter, we drop the samples from Eastern province in Kenya for the analysis below since we apply statistical methods relying on the longitudinal features of the data. In addition, attrition also reduced the number of households interviewed. As a result, out of the 777 targeted households, 725 households were revisited for the survey, resulting in an attrition rate of 6.7%.⁴

The surveys in Uganda cover 94 rural Local Council 1 areas (LC1s) that are located across most regions in Uganda, except the North where security problems exist.⁵ From each rural LC1, 10 households are randomly selected, resulting in a total of 940 small farm households. The second round was conducted in 2005, and 895 households out of the 940 original households visited in the first round were interviewed. Thus, the attrition rate was low at 4.8%.⁶

2.3.2 *Driving Time to the Nearest Maize Market*

To measure market access in Kenya and Uganda, we first locate all the sample households and the four maize markets, where we have the RATIN monthly maize price data, by using GIS position coordinates. We overlayed their positions on digitized road maps and selected the shortest route from each household to the maize markets by using ArcGIS. We classify roads into four groups: trekking paths (no vehicles allowed), dirt roads (or dry-weather only roads), loose-surface roads (all-weather roads), and tarmac roads (all-weather roads, bound surface). Except for the trekking paths, we apply an average driving speed on each of the three road types and calculate the driving time from each household to each of the three markets. On the trekking paths, we calculate the walking time and add the walking time to the driving time. By comparing the driving time to the three maize markets from each sample household, we select the one that is quickest to reach in time as the nearest maize market for each household in Kenya. The computation results are likely to be longer than the actual travel time since walking speed is assigned to all paths except for roads. Additionally, the types of land cover and the slope of the land are taken into account so as to deflate the driving and walking speed.

In Uganda, there is only one maize market (i.e., Kampala) where we have adequate monthly price data. In eastern Uganda, however, maize farmers export maize

⁴We estimated the determinants of the attrition from the surveys and found that none of the independent variables is significant at the 5% level. Thus, we think that the attrition mostly occurred randomly and do not expect serious attrition biases.

⁵The surveys in Uganda were conducted jointly by Makerere University, Foundation for Advanced Studies on International Development (FASID), and National Graduate Institute for Policy Studies (GRIPS).

⁶The attrition rate is less than 5%. None of the independent variables in the determinants of the attrition model is significant even at the 10% level. Thus, we do not think that the attrition biases are serious.

to Kenya. Thus, the nearest market in the area may not be Kampala but Kisumu, which is the third largest city in Kenya and is located near the Kenya–Uganda border. Indeed, preliminary analyses indicate that the regression models, which are presented later in this chapter, perform better if we match the Ugandan farmers in the eastern regions with the Kisumu market rather than the Kampala market. Thus, we select Kisumu as the nearest maize market for some Ugandan households that live closer to Kisumu than to Kampala.

In almost all of our Kenya and Uganda sites, there are two cropping seasons. For each cropping season, we need to identify the monthly market prices that are comparable to the farm-gate prices that the maize farmers received after each harvest. From our own surveys, we know that most of our sample households sell their maize within 4 months after their harvests. Thus, after matching our sample households with the nearest maize market, we calculate the average market price during the 4 month postharvest season and match them with the maize farm-gate price data obtained from the household surveys. Note that in our surveys we have asked our respondents about the previous two cropping seasons. In Kenya, we conducted our surveys during the January–March period in 2004 and 2007. Thus, we have price data pertaining to two cropping seasons in the previous year of each survey, i.e., 2003 or 2006. In Uganda, we conducted our surveys during the August–October period in 2003 and 2005. Thus, the cropping seasons that are covered in our surveys are the first cropping season of the survey year and the second cropping season of the previous year of each survey. Note that because survey years are different in Kenya and Uganda, the corresponding market maize prices are different in the two countries.

2.4 Descriptive Analyses

To begin our analyses, we first look at the monthly maize price data in the four maize markets in Kenya and Uganda shown in Figs. 2.2 and 2.3. In Fig. 2.2, we present the monthly maize price data in Nairobi and Eldoret from January 2001 to January 2007. Nairobi is the capital and the largest city in Kenya and, therefore, is the largest maize deficit city in the country. Eldoret, on the other hand, is located in Rift Valley, which is the main maize producing area. Many medium and large-scale commercial maize farmers are located in Rift Valley Province. Thus, Eldoret is one of the largest maize surplus markets in the country. In Fig. 2.2, therefore, we can clearly see that the monthly price at Eldoret tends to be lower than the monthly price at Nairobi. We also notice a seasonal pattern in the figure: the gap tends to be large during the period from October to January, which follows the maize harvest season in Rift Valley. In Fig. 2.3, we compare the monthly maize prices at Kisumu in Kenya and Kampala in Uganda. We can clearly see that the maize price is higher in Kisumu than in Kampala. The gap between the two prices was larger than \$70 per ton in 2003 and 2004 but has shrunk in recent years. Ugandan farmers who are located in between these markets can benefit from the higher maize price at Kisumu

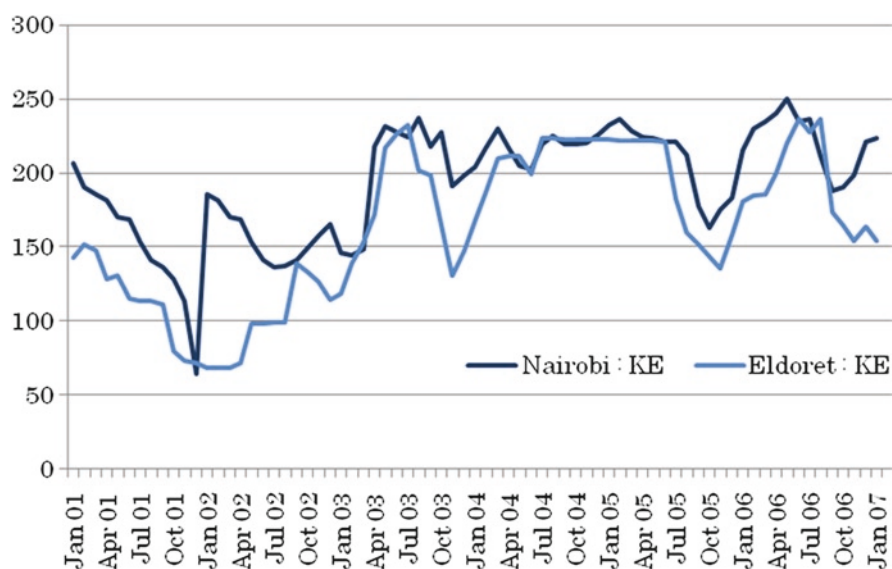


Fig. 2.2 Monthly maize price at Nairobi and Eldoret from January 2001 to January 2007

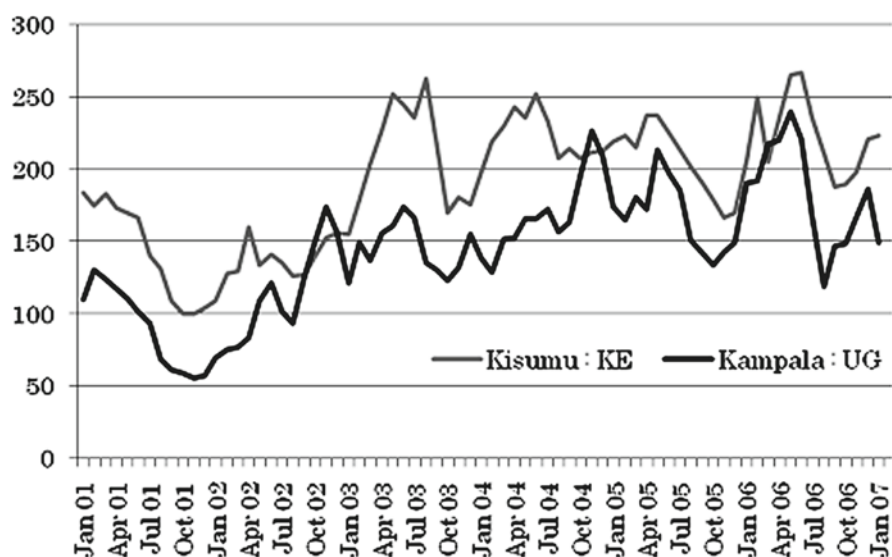


Fig. 2.3 Monthly maize price at Kisumu and Kampala from January 2001 to January 2007

than at Kampala. The shrinking price gap indicates the greater integration of the two markets over time due mainly to the marketing behavior of Uganda farmers.

In Table 2.1, we find that the average maize market price in the two harvest seasons in 2004 is about \$215 per ton in Nairobi. During the same period, the average

Table 2.1 Farm-market price spreads of maize in Kenya and Uganda

	2003/2004			2005/2007		
	Market price	Farm-gate price	Price spread % of (1)	Market price	Farm-gate price	Price spread % of (1)
Nearest market	(1)	(2)	(3)	(4)	(5)	(6)
<i>Kenya</i>						
Nairobi	215.4	162.6	24.7	203.7	168.2	17.4
Eldoret	211.0	145.6	31.0	161.4	153.4	4.9
Kisumu	227.5	174.2	22.5	211.2	194.5	7.3
All	217.9	160.6	26.1	195.3	171.9	11.4
<i>Uganda</i>						
Kisumu	188.1	106.4	43.4	187.2	98.4	47.4
Kampala	135.2	104.5	22.7	158.1	104.1	34.2
All	148.0	105.4	27.2	164.5	104.0	37.0

Survey years in Uganda are 2003 and 2005. Survey years in Kenya are 2004 and 2007

farm-gate maize price for farmers, who live closer to Nairobi than the other two maize markets in Kenya, is \$163 per ton. Thus, the farm-market price spread is about \$52 per ton, which is about 25% of the market price. In 2007, the average maize market price is \$204, and the farm-gate price is \$168. Thus, the farm-market price spread is about 17% of the market price.

As discussed earlier, Eldoret is located in a maize surplus area and usually has lower maize prices than in Nairobi. In Table 2.1, we find that the average maize price is \$211 per ton in 2004 and \$161 in 2007. These prices are lower than the Nairobi prices in both years, especially in 2007. Because the 2006 maize harvest was especially good in Rift Valley, the maize price declined in Eldoret, as we can see in Fig. 2.2. The farm-gate price remains at just below the market price and the price spread is only 5% of the market price.

In western Kenya, Kisumu is the largest city where a large quantity of maize is traded. In Kisumu, the average maize market price is higher than the one in Nairobi in the harvest seasons of 2004 and 2007: it is \$228 in 2004 and \$211 in 2007. The farm-gate price is higher in this area also: it is \$174 in 2004 and \$195 in 2007. The price spread in 2004 is 22.5% of the market price. As in the Eldoret area, the price spread declines considerably in 2007, to 7.3% in 2007. As a result, the average price spread for the whole sample in Kenya declines from 26.1% in 2004 to 11.4% in 2007.

In Uganda, the market maize price is much lower than in Kenya, as we have already discussed in Sect. 2.2. The average maize price in Kampala is \$135 in 2003 and 158 in 2005. The corresponding farm-gate price for maize farmers, who live closer to Kampala than Kisumu, is \$105 in 2003 and \$104 in 2005. Thus, the price spread is about 22.7% and 34.2% in 2003 and 2005, respectively. For those Ugandan farmers who live closer to Kisumu than Kampala, the farm-gate price is \$106 in 2003 and \$98 in 2005. Thus, compared with the market price in Kisumu, the price spread is about 43.4% and 47.4% in 2003 and 2005, respectively. Therefore, while

Kenyan farmers who live close to Kisumu are receiving farm-gate maize prices that are about 3–19% lower than the Kisumu price, Ugandan farmers across the border are receiving farm-gate prices that are more than 40% below the same Kisumu price. Since Ugandan farmers are located far away from Kisumu, the difference in distance to Kisumu may explain much of the difference. In order to examine the price spreads across countries and regions, we need to control for the driving hours to the nearest maize market from each household.

To analyze the relationship between the farm-market price spread and the driving time to the nearest maize market, we first draw a simple plot between the price spread, expressed as the percentage of the market price, and the driving time to the nearest maize market. To smooth the measurement errors over the years, we pool the data over the years for each country. According to Fig. 2.4, the farm-market price spread is lower in Kenya than in Uganda. In Kenya, the farm-market price spread is about 10% if maize farmers are located within two driving hours to the nearest maize market. The farm-market price spread starts increasing gradually to about 20% at five driving hours. In Uganda, even within one driving hour, the farm-market price spread is already about 30%. As the distance becomes longer, the price spread increases gradually to about 35% of the market price. The price spread increases only by 5% points over the five driving hour distance in Uganda, while it increases about 10% points in Kenya over the same distance.

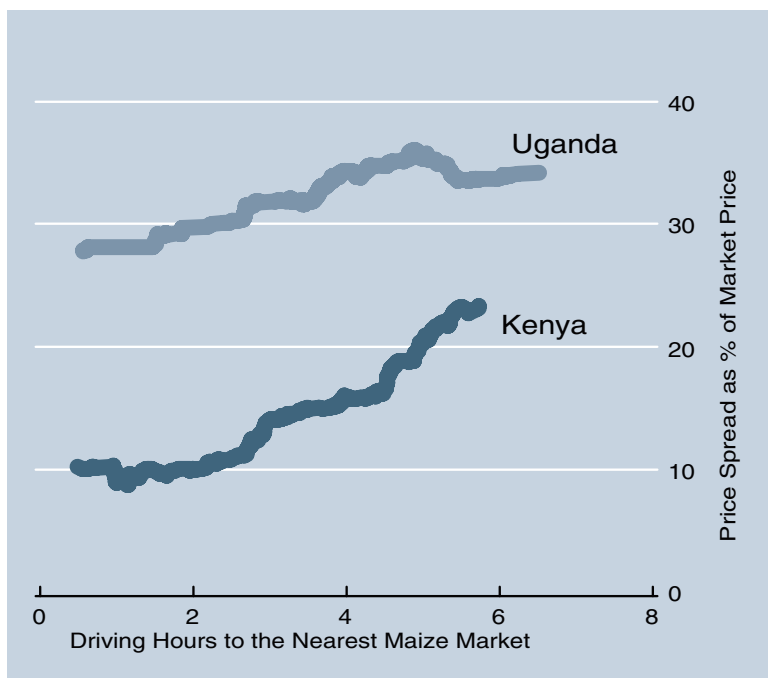


Fig. 2.4 Farm-market price spread as a percentage of market price by the driving time to the nearest marker in hours in Kenya and Uganda

Table 2.2 Maize price spreads by driving time to the nearest maize market

	All	Driving hours to the nearest maize market		
		0–2 h	2–4 h	Over 4 h
	(1)	(2)	(3)	(4)
<i>Kenya</i>				
Nairobi	20.4	15.6	14.0	28.1
Eldoret	19.7	15.4	18.8	22.1
Kisumu	15.4	21.4	11.5	39.2
All	18.7	17.6	13.1	25.8
<i>Uganda</i>				
Kisumu	45.2	n.a.	49.5	43.0
Kampala	29.2	25.3	29.8	29.3
All	32.7	25.3	32.9	33.6

In Table 2.2, we divide the samples into three groups according to driving time to the nearest market: 0–2 h, 2–4 h, and over 4 h. As in the previous table, we further divide the samples by the nearest market. In this table, we find that the price spread widens as the distance to the nearest market increases. In the Nairobi area, the average farm-gate price is about 20% below the market price at Nairobi. The price spread is about 16% if maize farmers are located within a 2 h driving distance. The price spread somehow declines slightly to 14% in the next distance group but increases to 28% in the remote group (over 4 h). In Eldoret and Kisumu areas, we also find that the price spread is the largest in the most remote area, even though the second most remote group has the lowest price spread in the Kisumu area. In Uganda, the relationship between the price spread and the driving time to the nearest market is less clear. In the Kampala area, the price spread is larger in the second most remote areas than the least remote area, but the differences are small. In the eastern Uganda area, which is closer to Kisumu than Kampala, there are no households that are within a 2 h driving distance from a market. In the second most remote area, the price spread is about 50% of the market price in Kisumu, implying that the farm-gate price is about half of the market price. This is much lower than what Kenyan farmers who are located within the same time range from Kisumu receive. Their price spread is about 12% of the market price. Among the most remote groups, however, maize farmers in Kenya and Uganda near Kisumu receive about the same level of the farm-gate price, which is about 60% of the market price, as indicated by the price spread of about 40%.

These findings suggest that the low farm-gate price compared with the market price in Uganda is not only because of the long distance to the nearest market but other factors, such as market structure and competition, matter. For instance, the unit price of maize may differ depending on the total volume of sales, where large maize farmers fetch a higher per unit price from maize traders than small maize farmers. Thus, we need to control for household characteristics. As we discussed in Sect. 2.2, there may be more maize traders in Kenya than in Uganda and maize is traded more often. If maize marketing in Uganda improves its efficiency to the

Kenyan level so farm-gate prices would rise by 10% points compared to the market price, then the maize farmers in the country will gain \$14–\$18 per ton. Since the distance to market is not the only factor that affects the farm-gate to market price ratio, we further explore the determinants of the ratio through regression analyses.

2.5 Estimation Models and Variables

To measure the marketing efficiency across countries and over time, we use the farm-market price spread measured as the percentage of the market price. The farm-market price spread has been used in many studies before, as surveyed in Fackler and Goodwin (2002). We use the percentage figure, instead of the price spread itself, because we want to eliminate inflation and exchange factors from our measure of efficiency. Thus, the regression model we estimate is

$$PS_i = f(M_i, E_i, H_i, Y, S) \quad (2.1)$$

where PS_i is the farm-market price spread measured as the percentage of the market price; M_i is the market access variable measured by the driving time from household i to the nearest maize market; E_i is a set of agroecological variables; H_i is a set of household characteristics of household i ; Y is the year dummy for the second round; and S is the season dummy for the second season. PS_i is defined as

$$PS_i = \left[\frac{p_i^M - p_i^F}{p_i^M} \right] \times 100 \quad (2.2)$$

where p_i^M is the market price of maize at the nearest maize market for household i and p_i^F is the farm-gate price of household i . The dependent variable is always above zero in our data and can be over 100 when the farm-gate price exceeds the market price, which occurs in our data set. Thus, we use the OLS model to estimate the regression function.

The agroecological variables include PPE (precipitation over potential evapotranspiration ratio), altitude, soil fertility, and population density. The PPE is used as an index for agroclimate conditions such as rainfall and temperature (a higher PPE denotes a greater agricultural potential), which is obtained from the database contained in the Almanac Characterization Tool (Corbett 1999). When we conducted community surveys in 2003 and 2005, we obtained the GIS coordinates of each community center. Thus, the altitude is measured at the community level. In addition to these variables, we include a soil fertility variable in the model. As an index of the soil fertility, we use the soil organic matter (SOM) content. Because the SOM is available for just the subsamples, we could estimate the models with the subsamples only. This method, however, may create selection biases because the subsamples with the soil fertility data are not selected randomly.

Instead, we replace all the soil-related variables with zero and include an additional dummy variable for those households without soil data. To assure that our approach provides robust estimates, we estimate the same model for all the households and the reduced sample.

The household characteristics include human capital and asset variables. The human capital variables include the age, education levels, and gender of the household heads. For household assets, we include own land size in hectares and the value of household farm equipments, furniture, transportation means, communication devices, and other household assets. Because the size and the soil fertility of the land are separately included in the model, we do not add the value of land to the total asset value.

2.6 Results

The estimated coefficient of the driving time in column 1 of Table 2.3 is 2.1 for Kenya, suggesting that the maize price spread increases by 2.1% points against the market price as the driving time increases by 1 h. In Fig. 2.4, we find that the price spread increases from 10% to 20% of the market price as the driving time increases by 5 h in Kenya. Thus, the estimation result is largely consistent with what we find in Fig. 2.1 for Kenya. The estimation result for Uganda is similar to that for Kenya: one additional driving hour increases the price spread by 2.3% points against the market price in Uganda. As we have seen in Fig. 2.4, maize farmers, in Uganda, who are located 5 h away from the nearest market receive at least a 10-percentage-point lower maize price than maize farmers who live near the market. These findings indicate that the marginal transportation cost associated with an increase in driving time affects the price spread equally between Kenya and Uganda, which may be taken to imply that local maize markets function well over the two countries.

None of the agroecological variables has significant coefficients. Thus, the agroecological variables do not affect the price spread between the farm-gate price and the market price, although they may affect the maize output price levels. Moreover, none of the household characteristics has significant coefficients in Kenya. Thus, as far as the maize market in Kenya is concerned, there is no indication of market imperfections, which supports Hypothesis 1, discussed in Chap. 1, that markets function well. In Uganda, young household heads and those who have more household assets have lower price spreads, i.e., higher farm-gate prices than others. One possible way for them to receive a higher price is to transport maize to a market where they can fetch a higher price. This is possible if the maize market is not well developed in Uganda. If the maize market is well developed, individual farmers do not need to transfer maize to a market because traders can do so at a lower cost than individual farmers. Such market imperfections in Uganda may explain why the price spread is much larger in Uganda than in Kenya, which is shown in Fig. 2.4.

Table 2.3 Determinants of price spread ratio in Uganda and Kenya.
(Dependent variable = (Market price – Farm-gate rice) × 100 / Market price)

	Kenya	Uganda
	(1)	(2)
<i>Market access</i>		
Driving hours to the nearest market	2.099** (2.78)	2.300*** (3.95)
<i>Agroecological variables</i>		
PPE	7.508 (1.20)	–5.374 (–0.50)
Altitude	–0.001* (–1.73)	0.001 (0.14)
Soil fertility	–0.727 (–1.21)	0.108 (0.12)
Population density	0.002 (0.84)	0.005 (1.35)
<i>Household characteristics</i>		
Household head age	0.092 (1.39)	0.129** (2.94)
Household head education	0.177 (0.79)	–0.221 (–1.28)
Female headed household	–0.095 (–0.04)	–3.005 (–1.56)
Land size in ha	–0.051 (–0.35)	–0.071 (–0.92)
ln (household assets)	–0.492 (–0.73)	–1.838** (–2.80)
Year dummy	–6.850*** (–12.11)	4.906*** (8.37)
Season dummy	–21.34*** (–9.76)	1.062 (0.90)
Constant	13,764*** (12.13)	–9,802*** (–8.34)

Absolute value of *t* statistics in parentheses

* Significant at 10%; ** significant at 5%; *** significant at 1%

2.7 Conclusions

To reduce poverty in rural areas, rural communities need to be integrated with markets so that they can receive high and stable returns to their agricultural products, thereby becoming less vulnerable to production shocks. Although there have been many studies that test market integration across markets by using time series price data, few studies have examined the price spread between market and farm-gate prices across countries by using panel data. Because poor transportation infrastructure is considered to be a major factor behind the high marketing costs in Africa, we examine the relationship between the farm-market price spread and driving time

from each sample household to the nearest maize market where we have monthly maize price data. The findings in this chapter indicate that there are substantial price spreads between farm gates and markets, which strongly suggests that the farm-gate price can be raised significantly by improving road conditions.

We also found that in both countries, the price spread increases equally by 2% points for one additional hour of driving time from the nearest maize market. Furthermore, we found that agroecological variables and household characteristics are generally insignificant in the price spread regressions, except for a few variables in Uganda. Although far from concrete, these findings indicate that local maize markets function well except in Uganda where there still remain some market imperfections. In order to reduce rural poverty, policies to reduce transportation costs and facilitate market competition are called for, particularly in Uganda.

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Chapter 3

Fertilizer Policies, Price, and Application in East Africa

Takashi Yamano and Ayumi Arai

Abstract In this chapter, we investigate the determinants of inorganic fertilizer use on major cereal crops in Kenya, Ethiopia, and Uganda. By using panel data in the three countries, we estimate the determinants of the fertilizer price and application at the household level and evaluate the fertilizer policies in each country. The determinants of the DAP price and application in Kenya can be mostly explained by market forces and agroecological factors, suggesting that market-based policies would be effective. In Ethiopia, on the other hand, the estimation results indicate that policy-related factors determine the fertilizer price and application. Although the subsidy program in Ethiopia may contribute to poverty alleviation, technical returns from such programs could be low. Uganda should learn from the experience from these two neighboring countries.

Keywords Fertilizer price • Fertilizer policy • Kenya • Uganda • Ethiopia

3.1 Introduction

While the intensity of the fertilizer use has rapidly increased in other parts of the world, it has remained at a low level in Sub-Saharan Africa. For instance, while it has increased from 38 kg/ha in 1982 to 101 kg/ha in 2002 in South Asia, it increased little during the same period in Sub-Saharan Africa. This negligible fertilizer use partly explains lagging agricultural productivity growth in Sub-Saharan Africa (Morris et al. 2007). Thus, experts and policy makers agree on the urgent need to increase the use of inorganic fertilizer in the region. There is less consensus on how

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to address this issue and currently there are marked differences in policies and programs pertaining to fertilizer use among African countries.

In the 1970s and early 1980s, many African countries adopted state-led fertilizer distribution policies where governments were heavily involved in fertilizer supply schemes via public agencies. During this period, the fertilizer use increased significantly, along with increased adoption of improved seeds, thereby raising hopes for some countries to follow the Asian Green Revolution (Eicher 1995; Byerlee and Eicher 1997). However, because of heavy financial burdens to support state-led policies, such as through subsidies or credit that was written off, many public agencies accumulated debts over years. As a result, during the following structural adjustment period in the late 1980s and 1990s, many governments adopted market reform policies, although the degree of how thoroughly these have been implemented varies from country to country (Jayne et al. 2003). Therefore, the results of the market reform policies are mixed and controversial, which provides opportunities to draw lessons on how to increase fertilizer use in the region.

In this chapter, we investigate the determinants of inorganic fertilizer use on major cereal crops in Kenya, Ethiopia, and Uganda. The fertilizer policies in the three countries are very different. Kenya is one of a few African countries, if not the only one, which has thoroughly and successfully implemented fertilizer market reform policy (Omamo and Mose 2001; Freeman and Kaguongo 2003). The Ethiopian government, on other hand, reversed its market reform policy and has been heavily involved in a fertilizer credit program in recent years, as will be described in Chap. 4 (and also in Spielman et al. (2010)). Finally, in Uganda, the fertilizer market has never expanded to a significant level, and thus its fertilizer policy can only be described as ineffective. By using the panel data in the three countries, we estimate the determinants of the fertilizer price and use at the household level and evaluate the fertilizer policies in each country to draw lessons firstly for these East African countries and secondly for Africa in general.

This chapter is organized as follows: Sect. 3.2 describes the current fertilizer policies and their recent evolution in the three countries. Section 3.3 explains the panel data used in this chapter. Sections 3.4 and 3.5 present the descriptive analysis and regression results on the fertilizer application, respectively. Finally, we discuss the policy implications in Sect. 3.6.

3.2 Fertilizer Policies in East Africa

3.2.1 Kenya

From 1974 to 1984, a state parastatal, the Kenya Farmers Association (later Kenya Grain Growers Cooperative Union), had significant control over fertilizer procurement and domestic distribution. As a result, the Kenyan government had extensive controls over imports, pricing, and marketing of fertilizer using policy instruments such as price subsidies, price control, licensing of importers and distributors, and

import quotas (Freeman and Kaguongo 2003). Since the mid 1980s, however, the government encouraged private firms to enter the market, even though it maintained tight controls over the market in the beginning (Jayne et al. 2003). Because of uncertainty about possible government interventions, private firms were reluctant to enter the fertilizer market. In 1993, the government finally withdrew from the fertilizer market and abandoned price controls. Freeman and Omiti (2003) conclude that the market reform has improved farmers' access to the input through the expansion of private retail networks. As a result, the number of fertilizer retailers increased roughly from 5,000 in 1996 to 8,000 in 2000 (Jayne et al. 2003).

There are several reasons for the successful reform of the fertilizer market in Kenya. First, before the market reform period, the state-led fertilizer policies were successful in increasing the fertilizer use among smallholders. As a result, many farmers learned about new technologies that involved high-yielding varieties and inorganic fertilizer. Second, before and during the market reform period, Kenya had strong cash crop sectors, which include tea, coffee, and sugarcane, and the sector has maintained a high and stable level of demand for fertilizer. Thus, fertilizer importers and distributors in the country were willing to make initial investments in facilities to import and store a large amount of fertilizer. These investment activities in the facilities have reduced retail prices of fertilizer for smallholder farmers. Third, farmers who planted cash crops received fertilizer credit from cooperatives and processing firms to apply fertilizer on cash crops. By using fertilizer on cash crops, they acquired knowledge on fertilizer and earned income to buy fertilizer to apply on food crops (Jayne et al. 2004). These factors have contributed to stable demand for fertilizer even during the transition period from the state-led fertilizer distribution system to private fertilizer market. Thus, the fertilizer consumption (in nitrogenous fertilizer) in the country has increased from 45,220 tons in the 5 year period of 1990–1994 to nearly 77,285 tons in the 5 year period of 2003–2007, which is the latest 5-year period where data are available (FAOSTAT 2010).¹

3.2.2 *Ethiopia*

In the early 1990s, Ethiopia reformed its fertilizer policy toward a free-market approach. The Ethiopian government liberalized and demolished the monopoly on fertilizer importation and distribution held by the parastatal Agricultural Inputs Supply Corporation (AISCO, then renamed the Agricultural Inputs Supply enterprise, AISE) (Spielman et al. 2010). The private sector initially responded rapidly, and, as a result, 67 private wholesalers and 2,300 retailers emerged. However, these

¹We use a 5-year period to examine fertilizer use trends because the fertilizer use fluctuates significantly year to year in many African countries. This is another sign of low and unstable demand for fertilizer in these countries.

private wholesalers and retailers quickly exited the market and were replaced by “private” holding companies with strong ties to government through the 1990s. As a result, only AISE and two regional holding companies accounted all fertilizer imports and distribution in 2001 (Jayne et al. 2003). Since 2007, fertilizer imports have been controlled by AISE and cooperatives. Regional governments in Ethiopia have also intervened in fertilizer supply, initiating a 100% credit guarantee scheme on farmers’ fertilizer purchase since 1994 (Spielman et al. 2010). Currently, it is said that about 90% of fertilizer is delivered on credit at below-market interest or even at zero interest, resulting in a steady increase in the total fertilizer consumption in the country. In fact, the total consumption (of nitrogenous fertilizer) had increased from 49,996 tons in the 5-year period of 1993–1997 to 78,443 tons in the 5-year period of 1998–2002, although it has since declined to 31,861 tons in the next 5-year period of 2003–2007 because of high international fertilizer prices and budget shortages (FAOSTAT 2010).

Thus, the state-led policies appear successful until recent years in increasing fertilizer use in Ethiopia. Some concerns about the state-led policies, however, have been raised by experts. First, it is not clear how long the government can sustain expensive fertilizer credit programs. Second, the state-led policies have crowded out the private firms from the fertilizer market (Jayne et al. 2003), so that it is not clear whether a market-based system could have performed as well or better than the state. Third, the increased fertilizer use coupled with the use of improved seeds has not necessarily achieved high technical efficiency and profits in Ethiopia, as found in Spielman et al. (2010) and Chap. 4 in this book. Spielman et al. (2010) argue that the low technical efficiency is largely due to the application of standard packages to vastly diverse environments, thereby resulting in nonoptimal use of these packages by many farmers. Furthermore, state-dominated inputs supply and credit systems failed to deal with the timeliness and quality of input supply. A study cited in Spielman et al. (2010), finds that half of sample farmers surveyed reported that fertilizer arrived after planting, 32% reported underweight bags, and 25% complained of poor quality.² In short, the Ethiopian government has failed to establish an efficient fertilizer distribution system, in contrast to the Kenyan government.

3.2.3 *Uganda*

Uganda has taken a completely different path from the two countries discussed above. When the other two governments were heavily involved in the fertilizer distribution in the 1970s and the early 1980s, the Ugandan government was deeply involved in civil conflicts and unable to implement any meaningful agricultural policies. By the time the Museveni government took over in 1986, the structural

²There is also a speculation that the Ethiopian government uses the fertilizer and credit subsidies to maintain political power over regional governments.

adjustment programs had started in other African countries, and the Uganda government quickly adopted such policies. Indeed, the Ugandan government was considered as a leading example of market reform policies for other countries to follow. However without a basic market structure to build upon, the scale of fertilizer market has never been large enough to capture any scale economies. Omamo (2003) found that the fertilizer market structure was dominated by small-scale trade, high prices, and low net margins in the early 2000s. This is likely due to the poor transportation infrastructure and the country's remoteness from the major ports. There is no sign of expansion of the fertilizer market for decades. The total fertilizer consumption (in nitrogen fertilizer) remains at a low level: the 5-year average in Uganda is only 3,842 tons, which is about 5% of the Kenyan fertilizer consumption and 12% of the Ethiopian fertilizer consumption (FAOSTAT 2010). The fertilizer policy debate in Uganda has been centered around the question of whether Uganda should follow the pathway of Kenya or rather the one of Ethiopia.

3.3 Data and Descriptive Analyses

3.3.1 *Data and Fertilizer Use*

The data used in this chapter come from household surveys in Kenya, Ethiopia, and Uganda collected as part of the Research on Poverty and Environment and Agricultural Technology (RePEAT) Project (see Chap. 2 for details). All of the RePEAT surveys employ similar questionnaires designed to be comparable, especially on agricultural production. The surveys in Kenya were conducted in 2004 and 2007 and cover 899 and 777 households, respectively. The second wave of the Kenya survey revisited all of the first wave sample households, except in Eastern Province. This is why the total sample size in the second wave is significantly smaller than the first wave. The surveys in Ethiopia were conducted in 2004 and 2006. The sample size is 417 in 2004, and 411 households out of the 417 households were reinterviewed in 2006. The surveys in Uganda covered 940 households in 2003 and 936 households in 2005.

We present the basic information about fertilizer use among our samples in Table 3.1. In column C, we find that the total amount of inorganic fertilizer use is over 100 kg per household in Kenya and Ethiopia. This is high compared with other African countries. Uganda is an example of the opposite situation: the total amount of inorganic fertilizer use is less than 10 kg per household. The differences in the amounts of fertilizer use in these countries largely reflect the differences in fertilizer policies of the countries. As mentioned earlier in this chapter, the fertilizer market has been privatized and expanded successfully in the past decades in Kenya. Farmers apply inorganic fertilizer on several crops, including cash and food crops. Table 3.1 provides some evidence for such a wide demand for fertilizer: Kenyan farmers apply several types of fertilizer on their crops. The most popular type is

Table 3.1 Sample households in Kenya, Ethiopia, and Uganda

			Proportion of inorganic fertilizer users	Average quantity used	Proportion of users by fertilizer type				Proportion of households that received credit
Country/survey year		Number of households			DAP	CAN	NPK	UREA	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	
	Number	%	kg	%	%	%	%	%	
Kenya	2004	899	81	134	78	33	28	11	21
	2007	777	78	121	70	19	25	8	18
Ethiopia	2004	417	74	104	71	–	–	71	44
	2006	411	73	113	69	–	–	43	64
Uganda	2003	940	7	4	1	1	2	3	–
	2005	936	8	7	3	1	4	3	–

Table 3.2 Sources of the fertilizer credit

	Kenya		Ethiopia		Uganda	
	2004	2007	2004	2006	2003	2005
	%	%	%	%	%	%
Cooperatives and farmer groups	90	68	35	67	–	–
Government agencies	0	29	56	27	–	–
Traders	8	2	8	5	–	–
Others	2	1	1	1	–	–
Total (%)	100	100	100	100		
[Number of households]	[213]	[267]	[187]	[147]	–	–

DAP: more than 70% of the sample households use at least some DAP. They also use CAN (19–33%), NPK (25–28%), and urea (8–11%). It is important to note that Kenyan farmers apply DAP and urea on cereal crops such as maize and apply CAN and NPK on cash crops such as tea, coffee, and sugarcane.

Cooperatives and processing firms of the cash crops often provide fertilizer credit to farmers. This is reflected in the fact that about 20% of the sample households received credit for fertilizer in Kenya. In Table 3.2, we find that 90% and 68% of those who received fertilizer credit in 2004 and 2007, respectively, received it from cooperatives and farmer groups. In 2007, government agencies provided fertilizer credit to 29% of those who received fertilizer credit. This is probably because of emergency public support programs to farmers who were suffering from high fertilizer prices due to extremely high international oil prices in 2007.

In contrast to the Kenyan situation, in Ethiopia, farmers use only DAP and urea, the two types of fertilizers that are heavily subsidized. About 70% of the sample households in Ethiopia use DAP. The corresponding percentage for urea is 71 and 43% in 2004 and 2006, respectively. In column H of Table 3.1, we find that 44 and 64% of the sample households in Ethiopia received credit in 2004 and 2006, respectively. As we can see in Table 3.2, the credit is supplied mostly from government

agencies and cooperatives. In 2004, about 56% of those who received fertilizer credit received it from government agencies, and 35% received it from cooperatives and farmer groups. In 2006, the proportion is 27% from government agencies and 67% from cooperatives and farmer groups. Because the cooperatives and farmer groups are also supported by government agencies, these numbers indicate that more than 90% of those who obtained fertilizer on credit received it from government-sponsored organizations.

Compared with Kenya and Ethiopia, the little use of inorganic fertilizer in Uganda is striking. One reason for this is the lack of credit in Uganda. No households in our Ugandan sample households received credit from any sources to buy inorganic fertilizer in 2003 and 2007. There is neither a large-scale government fertilizer program, like in Ethiopia, which provides subsidized fertilizer to farmers nor an active private fertilizer sector, like in Kenya, which supplies fertilizer at competitive prices. Since Uganda is landlocked and the transportation system connecting it to ports is poorly developed, access to the fertilizer market is unfavorable in this country.

3.3.2 Crop and DAP Prices

To provide basic information about the DAP price distribution in each country, we present box plots of the DAP price in Fig. 3.1. The number of DAP price observations is so small in Uganda that the Ugandan boxes are undetectable. The horizontal

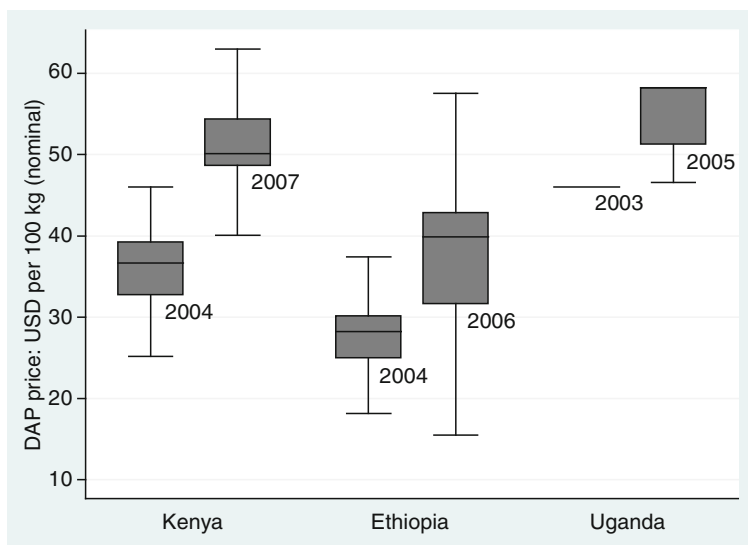


Fig. 3.1 Box plots of DAP price in Kenya, Ethiopia, and Uganda (The top and bottom of each box represent 75th and 25th percentile, respectively. The horizontal line in each box represents the mean value)

line of the first (far left) box in Fig. 3.1 represents the average DAP price in Kenya during the first survey period in 2004. The top and bottom of the box represent the 75th and 25th percentiles of the DAP price. By comparing boxes in Fig. 3.1, we note that the Kenya boxes are smaller than the Ethiopian boxes, indicating smaller price variations in the DAP price in Kenya than in Ethiopia. As we discussed before, the fertilizer market is liberalized and functions well such that fertilizer traders and retailers tend to equalize the DAP prices across regions. In Ethiopia, the fertilizer price is subsidized not by the federal government but by the regional governments. Thus, the large variations in the fertilizer price may suggest differences in the subsidies across regions.

What matters to farmers, however, is not the fertilizer price itself. Even if the fertilizer price is high, farmers can make profit if the output price is also high. What matters most is the price ratio of input and output prices. Thus, to examine economic returns from inorganic fertilizer use on cereal crops, we present in Table 3.3 various cereal crop prices, the DAP price, the price ratios of the two, and the proportions of households that applied DAP on crops. First, we compare prices of maize across countries. In Kenya, the maize price per 100 kg is \$15 in 2004 and \$17 in 2007. The DAP price increased significantly from \$35 in 2004 to \$50 in 2007. As a result, the input–output price ratio increased from 2.3 in 2004 to 3.0 in 2007. Despite the increase in the real DAP price, the proportion of the farmers who apply DAP in 2007 remains high at 81%, only a 6-point decline from 2004.

The maize price in Ethiopia and Uganda is about two thirds of that of Kenya. In Ethiopia, it is \$11 and \$13 per 100 kg in 2004 and 2006, respectively. Due to the subsidy program in Ethiopia, the DAP price is kept at a low level: it is \$27 and \$36 per 100 kg in 2004 and 2006. Thus, despite the low maize prices, the input–output price ratios are at a low level and are comparable to those in Kenya. The proportions of farmers who apply DAP on maize, however, remain low at 24% in 2004 and 48% in 2006 and are much lower in Ethiopia than in Kenya. Without a fertilizer subsidy program, the DAP price is higher in Uganda than in the other two countries. It is \$37 and \$47 per 100 kg in 2003 and 2005, respectively. Even these prices underestimate the real DAP price in Uganda because these prices are calculated from farmers who have applied fertilizer. They mostly live near the Uganda–Kenya border. In other parts of Uganda, few farmers use fertilizer, and we do not have fertilizer price information. We suspect that the fertilizer price must be higher in such nonconsuming areas in Uganda. Among the fertilizer users in Uganda, the input–output ratio is 3.4 in 2003 and 4.7 in 2005, which are much higher than in the other two countries, and virtually no farmers apply DAP on maize. What is important to note is that the fertilizer price is similar to Kenya among the Ugandan fertilizer users, but the maize output price is about two-thirds. The Uganda maize price would increase to the level close to the Kenya level, if maize markets are integrated across the country borders. (see Chap. 2).

On the other crops, situations are similar to maize. The output prices are higher in Kenya than in Ethiopia, and, as a result, the input–output price ratios are about the same in these two countries. For instance, the wheat price is \$20 per 100 kg and

Table 3.3 Crop and DAP prices and proportions of DAP users

	Crop price		DAP price		Price ratio (B)/(A)		Proportion of households that used DAP	
	2003–2004	2005–2007	2003–2004	2005–2007	2003–2004	2005–2007	2003–2004	2005–2007
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	USD/100 kg		USD/100 kg		Ratio		%	
<i>Maize</i>								
Kenya	15.3	16.7	34.9	50.0	2.3	3.0	87	81
Ethiopia	10.9	13.0	27.0	36.2	2.5	2.8	24	48
Uganda	10.9	9.9	37.1	46.8	3.4	4.7	1	2
<i>Wheat</i>								
Kenya	20.1	25.4	33	48.9	1.6	1.9	52	50
Ethiopia	14.0	20.8	27.8	38.0	2	1.8	61	67
<i>Teff</i>								
Ethiopia	22.6	32.6	27.2	37.1	1.2	1.1	67	59
<i>Sorghum</i>								
Kenya	24.4	16.6	34.1	49.7	1.4	3	53	55
Ethiopia	15.8	20.4	31.5	32.5	2	1.6	6	16
<i>Millet</i>								
Kenya	28.3	30.9	35.3	49.8	1.2	1.6	41	34
<i>Ave. price</i>								
Kenya	16.4	17.7	35.4	50.0	2.2	2.9	n.a.	n.a.
Ethiopia	17.7	25.4	28.0	33.3	1.6	1.3	n.a.	n.a.
Uganda	10.9	9.9	44.9	49.2	4.1	5.0	n.a.	n.a.

Survey years in Uganda are 2003 and 2005.

Survey years in Kenya are 2004 and 2007.

\$25 in 2004 and 2007, respectively, in Kenya, while it is \$14 and \$21 in 2004 and 2006, respectively, in Ethiopia. The DAP price, however, is about 20% lower in Ethiopia than in Kenya. Thus, the input–output price ratio is about 2 in both countries. The proportions of wheat farmers who apply DAP also are high in both countries at over 50% in Kenya and 60% in Ethiopia.

Teff is arguably the most important cereal crop in Ethiopia. It is the main ingredient of the national staple food, Injera. The output price of teff per 100 kg is much higher than other cereal crops: it is \$23 and \$33 in 2004 and 2006, respectively. As a result, the input–output ratio is much lower for teff than the other crops: it is only 1.2 in 2004 and 1.1 in 2006. Thus, the unit price of teff is as much as the DAP unit price. The proportions of farmers who apply DAP on teff is high at 67% in 2004 and 59% in 2006, similar to those for wheat. Given the very low input–output price ratio, we may expect that the proportions of the DAP users would be higher among teff farmers than wheat farmers. However, one reason why this is not observed is the low response to DAP and other inorganic fertilizers of teff. Although international agricultural research centers, such as International Maize and Wheat Improvement Center (CIMMYT), have been improving wheat seeds for Sub-Saharan Africa for many decades, no international agricultural research centers conduct research on teff because Ethiopia is virtually the only country to produce teff in the world. Thus, although there exist improved seeds of teff, the fertilizer response rate of such seeds remains low. In addition, Ethiopian farmers prefer planting traditional varieties of teff because consumers value the taste of such varieties.

Because farmers in the three countries produce several cereal crops, it would be too complicated to examine how all crop prices affect the fertilizer applications. To simplify our analysis, we calculate a weighted average price per kg of all cereal crops produced in each country and compute a DAP-composite crop price ratio. We use production quantities of all crops as weights. Although all crops have different production returns to DAP applications and market values per unit, using the weighted average makes it possible for us to compare the estimation results across the three countries. The results in Table 3.3 show that the weighted average price of cereal crops is about \$16–17 per kg in Kenya. The weighted average price is less than half of the DAP price, and the DAP–crop ratio becomes 2.2 and 2.9 in 2004 and 2007, respectively. These ratios are close to the ratios for maize and are consistent with our expectations because maize is the dominant cereal crop in Kenya. In Ethiopia, the weighted average crop price is about \$18–25. In Ethiopia, three cereal crops, i.e., teff, wheat, and maize, are widely cultivated. This is why, the average weighted price is in between the price of teff and the other crop prices. In Ethiopia, the DAP–crop ratio is 1.3–1.6 and is the lowest among the three countries because of the subsidized DAP prices. In Uganda, the weighted average crop price is much lower than the ones in the other two countries: it is about \$11 and \$10 per kg in 2003 and 2005, respectively. As a result, the DAP–crop ratio becomes 4.1 in 2003 and 5.0 in 2005. Thus, the DAP–crop price ratio in Uganda is more than two times higher than the one in Ethiopia and at least 70% higher than the one in Kenya.

3.4 Estimation Models and Variables

3.4.1 Estimation Models

First, we estimate the determinants of the DAP price paid by farmers in the three countries. The dependent variable is measured for each purchase of DAP by sample households. The estimation model is

$$\text{DAP Price} = f(\text{Market Access, Agro - ecological Conditions, Household Characteristics, Country, and Second Round dummies}) \quad (3.1)$$

We estimate this model for pooled data of the three countries and for each country separately. We expect that the DAP price would be higher in areas with poor market access because of high transportation costs. As proxies for market access, we include two variables. One is the driving hours to the nearest city, and the other is the driving hours to the capital. The driving hours to the capital controls for overall market conditions. Crop and DAP prices at any urban center are affected by the driving time to the capital. If farmers are located farther away from the urban center, however, the prices that they receive for crops could be much lower than the market prices. Thus, the driving hours to the nearest urban center measures the local market access.

Agroecological conditions also affect demand for DAP. For instance, in high-potential areas, the demand for DAP would be high. However, in such areas, the supply of DAP would also be high, likely involving more traders. As a result, per unit cost of DAP transportation may be low. It is not clear, therefore, if the DAP price would be relatively high or low in high-potential areas.

If the DAP price is determined purely by market forces, household characteristics should not influence the price. We expect, however, that some household characteristics affect the DAP price even under well-functioning markets because of our procedure to compute per unit price. Some farmers purchase DAP and other inorganic fertilizer in large packages, such as 50 or 100 kg bags, while others purchase it in small packages. Because small packages require a similar transaction cost as large packages, the price per kilogram would be higher for small packages. Since well-off households tend to purchase agricultural inputs in large packages, we expect to find negative effect on price of some household variables, such as land size or asset values. Other household characteristics that are not correlated with the size of fertilizer purchases should not be correlated with the DAP price.

Next, we estimate the determinants of the DAP application per hectare. The estimation model is

$$\text{DAP use per ha} = f(\text{DAP - Crop Price Ratio, Market Access, Agro - ecological Conditions, Household Characteristics, Country and Second Round dummies}) \quad (3.2)$$

Again, we estimate this model for the pooled data and for each country. In this model, we add one variable, which is the DAP–crop price ratio. Because farmers apply DAP on various crops, we calculate the weighted average of crop prices by using quantities of crop productions as weights, as we have shown in Table 3.3. Then, we calculate the DAP–crop price ratio aggregated up to the district level. This is done because we do not have DAP price data from farmers who do not purchase it. Without the DAP price, we cannot estimate the Eq. 3.2 for those who do not use DAP. Thus, we aggregate the DAP price up to the district level and assume that all farmers face the same price within district at a given agricultural season, and divide the DAP price by the weighted average of the crop prices.

Although we expect that the DAP price has a negative impact on DAP fertilizer use, there are some factors that work against this effect. For instance, the DAP price is subsidized in Ethiopia, as discussed earlier. Thus, the DAP price is artificially low in Ethiopia, although the amount of the fertilizer use is about the same or lower than in Kenya, as we can see in Table 3.1. The low fertilizer price in Ethiopia, therefore, makes it difficult to identify the relationship between the DAP price and DAP use in the pooled data. Even within Ethiopia, the DAP price is determined by regional governments. They may set the DAP price low in areas where farmers do not use much DAP to encourage them to use it. In this case, we would find a reverse causality between the DAP price and use. Therefore, we must be careful about interpreting the results of our analyses.

3.4.2 Variables

As mentioned earlier, to measure the market access, we calculate the driving time in hours to the nearest urban center (above 25,000 inhabitants). First, we overlay positions of sample households on digitized road maps and select the shortest route from each household to urban centers by using ArcGIS. We classify roads into four groups: trekking paths (no vehicles allowed), dirt roads (or dry-weather only road), loose-surface roads (all-weather road), and tarmac roads (all-weather road, bound surface). Except for the trekking paths, we apply an average driving speed on each of the three road types and calculate driving hours from each household to the nearest urban market. For the trekking paths, we calculate walking hours and add the walking hours to the driving hours. Types of land cover and slope of the land are taken into account so as to modify driving and walking speed. To capture other characteristics of locations, we control for the driving time to the capital and include it in the regression model. For samples in Uganda, we use the driving time to Eldoret in Kenya, instead of Kampala, because Eldoret is the main fertilizer market for the sample households that use at least some inorganic fertilizer in Uganda. To them, Eldoret is closer than Kampala, and inorganic fertilizer is cheaper in Eldoret than in Kampala. They sell maize in Kisumu in Kenya, however, because the maize price is higher in Kisumu than in Eldoret, which is a maize surplus city. On agroecological conditions, we include the altitude and the PPE (precipitation over potential

evapotranspiration ratio). When we conducted community surveys in 2003 and 2005, we obtained GIS readings at the center of each community. Thus, the altitude is measured at the community level. The PPE is used as an index to measure the agroecological conditions where a higher PPE means a greater potential for agriculture. The PPE is obtained from the database contained in the Almanac Characterization Tool (Corbett 1999). In addition to these variables, we include an index of soil fertility variable in the model, which is represented by the soil organic matter (SOM) content. We could estimate this model with the subsamples for which we have the SOM data. This method, however, may create selection biases because the subsamples with the soil fertility data are not selected randomly. Instead, we replace all the soil-related variables with zero and include an additional dummy variable for those households without soil data. To assure that our approach provides robust estimates, we estimate the same model for all the households and subsamples.

The household characteristics include human capital and asset variables. The human capital variables include age, education levels, and gender of household heads. For household assets, we include own land size in hectares and the value of household farm equipments, furniture, transportation means, communication devices, and other household assets. Because the land size and the soil fertility of the land are separately included in the model, we do not include the value of land in the total asset value.

There are two major limitations of the estimation models (please see Chap. 2 for more detailed discussions about these limitations). The first limitation is that we have at most one soil sample per household. Because of this limitation, we assume that the soil fertility is fixed over time and the same across plots that belong to each sample household in order to use all the observations in our panel data. The second major limitation of our estimation models is that, in addition to the soil fertility variables, the travel time to urban centers and the capital is also observed only once in our panel data. Moreover, these soil fertility and traveling time variables could be correlated with some omitted variables, such as farmers' ability (which could related to soil fertility). If we had multiple observations of these variables over time, with large variations, we could use a fixed effects model to control for unobserved household fixed effects and at the same time identify causal impacts as well. Without such multiple observations of the variables, we are unable to eliminate potential biases created by omitted variables to identify causal impacts. Thus, in this study, we interpret the results as observed associations between these independent variables and the outcome variables, instead of causal relationships between them.

3.5 Results

We first discuss the results of the market access variable. The first column of pooled regression in Table 3.4 indicates that the DAP price does not depend on market access or agroecological conditions. However, a quick look at the results in the

Table 3.4 Determinants of DAP price in log. The dependent variable is the natural logarithm of fertilizer price (USD) per ton

	Pooled (A)	Kenya (B)	Ethiopia (C)	Uganda (D)
<i>Market access</i>				
Hours to the capital ^a	0.00231 (0.50)	-0.00462 (-0.61)	-0.00284 (-0.30)	0.831*** (2.91)
Squared hours to the capital ^a	-0.000178 (-0.71)	0.0000261 (0.04)	-0.0000624 (-0.14)	-0.0656*** (-2.78)
Hours to the nearest city	0.00762 (1.35)	-0.00241 (-0.53)	0.0653*** (4.17)	
Squared hours to the city	-0.000752 (-1.39)	0.000684* (1.70)	-0.00706*** (-4.36)	
<i>Agroecological variables</i>				
PPE	0.0318 (1.48)	0.118*** (3.59)	-0.0216 (-0.54)	-0.230** (-2.12)
Altitude	-0.0000015 (-0.37)	-0.000012*** (-3.27)	0.0000052 (0.20)	-0.00022*** (-4.29)
Soil fertility (carbon)	0.00434 (1.01)	0.00167 (0.40)	0.000210 (0.02)	0.0727** (2.25)
<i>Household characteristics</i>				
Household head age	0.000264 (0.77)	0.000267 (0.84)	0.000338 (0.54)	-0.00214** (-2.04)
Household head education	0.00389*** (2.95)	0.000744 (0.73)	0.00974*** (3.33)	0.0116*** (2.90)
Female-headed households	0.0178 (1.30)	0.0145 (1.49)	0.0192 (0.56)	-0.101 (-1.55)
Land size	-0.00390** (-2.10)	-0.00670*** (-3.18)	-0.00169 (-0.52)	0.0683*** (3.19)
ln (asset value)	-0.0187*** (-4.30)	-0.00398 (-1.13)	-0.0302*** (-3.22)	-0.0798*** (-3.16)
<i>Country dummies</i>				
Second-round dummy	0.332*** (25.46)	0.330*** (40.89)	0.302*** (17.88)	0.349*** (6.83)
Constant	5.924*** (150.24)	5.888*** (139.63)	5.629*** (62.06)	6.495*** (50.10)
<i>F stat</i>				
<i>Market access</i>	1.80	1.40	5.78	0.62
<i>Agroecological variables</i>	0.93	4.63	1.62	9.79
<i>Household characteristics</i>	8.19	3.16	4.82	2.65
Number of samples	1,712	817	812	83

Absolute value of *z* statistics in parentheses

Country dummies and interaction terms between the country dummies and the second year dummy are included in the model but excluded from the table

* Significant at 10%; ** significant at 5%; *** significant at 1%

^aFor samples in Uganda, the hours to the capital measures the driving time to Eldoret, which is the main fertilizer market for Ugandan farmers in the eastern region

columns of individual country analyses shows that this is because individual countries have opposite results regarding the effect of market access. In Kenya, the DAP price does not depend on market access. This suggests that the DAP retail price remains at the same level across regions because of the well-developed network of fertilizer retailers. In Ethiopia, driving time to the capital does not have any effect on the DAP price, but driving time to the nearest urban center has a positive effect on the DAP price. This suggests that the government-supported fertilizer agencies set the base fertilizer price constant across regions, but add transportation charges to the costs to the farmers at the local level. In Uganda, we use the driving time to Eldoret, as a proxy of the market access, because farmers who use DAP in Uganda are living near the Kenya border and obtain fertilizer from Kenya. Eldoret is the nearest big city in Kenya for those Ugandan households that use fertilizer among our samples. The results indicate that the DAP price increases as the Ugandan households are located farther away from Eldoret.

Regarding the agroecological conditions, we find that they have an effect on DAP price in Kenya and Uganda but not in Ethiopia. In Kenya, the DAP price is higher in areas with a high PPE and also higher in lowland areas. Since lowland areas with a high PPE are generally high-potential agricultural areas, the results suggest that the DAP price is high in high-potential areas. In contrast, the agroecological conditions do not have any impacts on the DAP price in Ethiopia. This is because the DAP price is determined by the government-supported agencies that would not consider the agroecological conditions when they set the DAP price. In Uganda, the results are similar to the ones in Kenya, except one: the DAP price is low in highland areas. As mentioned earlier, in highland areas near Kapchorwa, which is a small town near Mt. Elgon located on the Kenya–Uganda border, farmers purchase fertilizer from Kenya. Because of easy access to Kenya, the DAP price in this area is lower than in other parts of Uganda. This is probably why we find a negative coefficient on the altitude in Uganda.

Among the household characteristics, land size and asset value have generally negative coefficients on the DAP price. The reason for the negative coefficients on the asset value and the land size is that wealthy large landholders tend to buy fertilizer in a large volume and have a low per unit cost. Thus, the unit price of DAP tends to be smaller for wealthy large landholders than poor small landholders. None of the other household characteristics have significant coefficients in Kenya. In Uganda and Ethiopia, however, we find that some household characteristics, in addition to land size and the total asset value, have significant impacts on the DAP price. This suggests that the fertilizer market is not well functioning in Uganda and Ethiopia so that some households find ways to buy inorganic fertilizer at different prices than others.

We expected the DAP–crop price ratio to have a negative coefficient on the fertilizer application. On the contrary, however, the pooled results in Table 3.5 indicate that the fertilizer price has a positive coefficient on the level of fertilizer application (column A). One of the reasons for this finding is that the fertilizer price is subsidized and artificially set low in Ethiopia. When we separate the samples and estimate the same model for each country, we find a negative coefficient on the

Table 3.5 Determinants of fertilizer use tobit model: the dependent variable is the quantity of fertilizer use (kg s) per hectare

	Pooled (A)	Kenya (B)	Ethiopia (C)	Uganda (D)
<i>Price ratio</i>				
Fertilizer/crop price ratio	27.73*** (4.44)	-103.6*** (-7.36)	102.5*** (9.66)	18.226 (0.79)
<i>Market access</i>				
Hours to the capital ^a	0.0744 (0.07)	14.93*** (4.90)	-3.163* (-1.89)	140.6 (1.49)
Squared hours to the capital ^a	-0.136*** (-2.64)	-1.445*** (-5.67)	0.00527 (0.08)	-8.997 (-1.45)
Hours to the nearest city	-0.440 (-0.29)	-3.206* (-1.65)	7.271** (2.51)	n.a.
Squared hours to the nearest city	0.163 (1.07)	0.363** (2.12)	-0.433 (-1.48)	n.a.
<i>Agroecological variables</i>				
PPE	3.237 (0.63)	58.52*** (5.19)	-20.23*** (-3.13)	-88.93 (-0.64)
Altitude	-0.00267** (-2.46)	-0.00191 (-1.61)	-0.00466 (-1.14)	0.181** (2.50)
Soil fertility (carbon)	1.460 (1.29)	3.324** (2.18)	-1.785 (-0.83)	21.43 (1.07)
<i>Household characteristics</i>				
Household head age	-0.180** (-2.14)	-0.168 (-1.27)	-0.0304 (-0.26)	0.0903 (0.08)
Household head education	0.586* (1.74)	-0.220 (-0.53)	1.849*** (3.16)	5.757 (1.50)
Female-headed households	-0.114 (-0.03)	-0.745 (-0.17)	-5.904 (-1.02)	2.820 (0.06)
Land size	0.233 (1.40)	-0.458 (-1.42)	0.204 (0.89)	1.372 (0.77)
ln (asset value)	4.905*** (4.40)	3.822** (2.54)	5.200*** (3.02)	9.257 (0.69)
<i>Country dummies</i>				
Second-round dummy	-9.749** (-1.95)	71.59*** (7.12)	3.761 (0.97)	59.64 (1.59)
Constant	-85.94*** (-5.77)	128.7*** (4.00)	-167.9*** (-7.91)	-1,256.2** (-2.54)
<i>F stat</i>				
Market access	8.77	10.53	5.95	1.68
Agroecological variables	12.75	2.03	10.24	2.14
Household characteristics	11.02	10.95	3.77	0.98
Number of samples	7,151	1,729	2,777	2,645

Absolute value of z statistics in parentheses

Country dummies and interaction terms between the country dummies and the second year dummy are included in the model but excluded from the table

* Significant at 10%; ** significant at 5%; *** Significant at 1%

^aFor samples in Uganda, the hours to the capital measures the driving time to Eldoret, which is the main fertilizer market for Ugandan farmers in the eastern region

DAP–crop price ratio in Kenya but a positive coefficient in Ethiopia. It appears that farmers in Kenya are responsive to the fertilizer price in determining the DAP use. In contrast, in Ethiopia, the government-supported agencies may set the DAP price high in areas where farmers are able to pay for high prices, while they set it low in areas where farmers are unable to pay for high prices. This is why we find a positive coefficient on the price ratio in Ethiopia.

From the above results on the DAP price, we suspect that fertilizer use in Kenya tends to be market-driven, while in Ethiopia it tends to be policy-driven. With this hypothesis in mind, we examine the estimation results on other variables. For instance, in Ethiopia, the results on the driving hours to the capital and the driving hours to the nearest urban center suggest that the DAP application declines in areas farther away from Addis Ababa, but the DAP application increases in remote areas once the driving hours to Addis Ababa is controlled. This result could be a result of regional governments' policies to encourage DAP use in remote areas in their regions. In Kenya, the DAP application increases in areas farther away from Nairobi. This is probably because the DAP application is high in Rift Valley, which is about 4–6 h away from Nairobi. Once we control for the driving hours to Nairobi, we find that the DAP application declines as the driving hours to the nearest urban center increases. This is what we expect in a normal market because the price ratio variable does not cover all the costs, such as transportation costs, associated with the distance to the nearest urban center; that effect is captured by the driving time to the nearest urban center.

Regarding agroecological conditions, we find that the DAP application is higher in areas with a lower PPE, hence low-potential, areas in Ethiopia. Again, this could be a result of a policy that encourages farmers to use DAP in areas where farmers have a low incentive to apply DAP. In contrast, we find that both the PPE and soil fertility have positive coefficients on the DAP use in Kenya. These results suggest that farmers in high-potential areas use more DAP than those who live in low-potential areas. In Uganda, both the PPE and soil fertility do not matter for DAP use, but the altitude has a positive impact on DAP use. This is probably because farmers in Kapchorwa are the primary users of DAP.

On household characteristics, we find that the total value of assets has a strong positive impact on the DAP use in both Kenya and Ethiopia. This suggests that farmers in Kenya and Ethiopia are facing credit constraints, despite the fertilizer credit programs available in both countries. Although we do not find a significant coefficient on the total value of assets in Uganda, this does not suggest that farmers in Uganda are not facing credit constraints. In Uganda, only farmers in the eastern regions, close to the Kenya–Uganda border, use DAP. Thus, even relatively well-off farmers in the central and western regions use little DAP. This is why, we do not find a positive coefficient on the total value of assets. Indeed, when we estimate the model with only the households in the eastern regions, we find a positive and significant coefficient on the total value of assets in Uganda.

Finally, we find that the education level of the household head has a positive impact on the DAP use both in Ethiopia and Uganda but not in Kenya. In Kenya, about 80% of the sample households use at least some inorganic fertilizer, as we

show in Table 3.1. Thus, farmers with various education levels are familiar with inorganic fertilizer, including DAP. Inorganic fertilizer use in Ethiopia and Uganda is not as widespread, as in Kenya. Although the government of Ethiopia is promoting the use of inorganic fertilizer with credit programs, farmers' knowledge about fertilizer use is still inadequate. Thus, educated farmers who have better knowledge about inorganic fertilizer tend to use more DAP than less educated ones. The results, therefore, suggest the need for extension services on how to use inorganic fertilizer in these two countries.

3.6 Conclusions

To identify constraints on inorganic fertilizer use, we have compared inorganic fertilizer application in three East African countries that have different fertilizer policies. Kenya is one of a few African countries, which have successfully liberalized fertilizer markets and achieved a substantial increase in the fertilizer use over decades. Ethiopia, on the other hand, has returned to state-led fertilizer marketing, after a brief liberalization of the fertilizer market, while Uganda's fertilizer market has remained minuscule. The estimation results in this study reflect the different fertilizer policies in the three countries. The determinants of the DAP price and application in Kenya can be mostly explained by market forces and agroecological factors, suggesting that the fertilizer market works well. One of the most important factors that affects fertilizer use in Kenya is the fertilizer price. The estimated results suggest that a relatively small reduction in the fertilizer price would lead to a large increase in the fertilizer use in this country.

In Ethiopia, on the other hand, the estimation results indicate that policy-related factors determine the fertilizer price and application. This is because Ethiopia has a large fertilizer subsidy program. As a result, the fertilizer use is high in low-potential areas, which tend to be in remote areas. Although such subsidy programs may contribute to poverty alleviation, technical returns from such programs could be low. As Chap. 4 in this book and Spielman et al. (2010) suggest, Ethiopia's state-led fertilizer policies may lead to nonoptimal use of fertilizer, which, in turn, would result in low returns to public investment. The Ethiopian government needs to start designing strategy to support the development of a private fertilizer marketing sector. As evidenced in other countries, there are different approaches for governments to take to encourage fertilizer use while still promoting the private sector. It may well be that the government should allocate more resources for the provision of pure public goods such as agricultural research and extension services, which may increase the effectiveness of fertilizer use and the demand for fertilizer. Finally, Uganda needs to learn from experiences in the two neighboring countries. Because it shares a border with Kenya, it is relatively easy to let the Kenyan fertilizer market expand into Uganda. As a result, the fertilizer prices would be close to the ones in Kenya. If the output prices remain low in Uganda, however, the fertilizer use would not increase. For instance, as Chap. 2 in this book describes, the maize market price

in Kampala, the capital city in Uganda, is about 30% lower than in Kisumu, which is located near the Ugandan border and is the third largest city in Kenya. The two countries need to eliminate explicit and implicit trade barriers on maize and other important staple crops to let Kenyan consumers buy cheap Ugandan crops and let Ugandan farmers buy cheap Kenya fertilizer.

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Chapter 4

The Impacts of Fertilizer Credit on Crop Production and Income in Ethiopia

Tomoya Matsumoto and Takashi Yamano

Abstract In this chapter, we evaluate the impact of fertilizer credit on crop choice, crop yield, and income using 2-year panel data of 420 households in rural Ethiopia. The fertilizer credit is found to increase input application for crop production. As a consequence, it has a substantial impact on the yield of teff. We also find that the impact on net crop income per cultivated area and also on per capita income is marginal because of the low profitability due to the low output price and high input cost of agricultural production.

Keywords Input credit • Fertilizer policy • Agricultural technology • Crop production • Ethiopia

4.1 Introduction

Ethiopia is not only one of the poorest countries in the world, but also one of the most populated countries: it is the 14th largest in the world and the second largest in Africa. To feed the large and growing population, agricultural production has to be increased by improving the agricultural productivity per land area because most of accessible fertile lands have been cultivated. To improve the agricultural productivity, the Ethiopian government has been implementing policies under the Sustainable Development and Poverty Reduction Program (SDPRP) and, more recently, the Plan for Accelerated and Sustained Development to End Poverty (PASDEP). In particular, Ethiopian regional governments initiated a 100% credit

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guarantee scheme on farmers' fertilizer purchases in 1994. Currently, it is said that about 90% of fertilizer is delivered on credit at below-market interest or even at zero interest. Subsequently, the total fertilizer use has increased from 250,000 tons in 1995 to 400,000 tons in 2008 (Spielman et al. 2010).

The credit scheme in Ethiopia, however, raises some concerns, as many other top-down credit schemes in developing countries do. First, the input distribution tied to credit may limit the emergence of private sector retailers, as pointed out by Jayne et al. (2003). Second, the public input distribution tends to deliver inputs that are of low quality and arrive too late. Spielman et al. (2010), for instance, quote a study that finds that half of the surveyed Ethiopian smallholders reported that their fertilizer arrived after planting, and 25% complained of the poor quality of the fertilizer they received. Third, the application of standard packages to very diverse environments in Ethiopia may lead to a low efficiency of fertilizer use. Thus, it is very important to evaluate the impact of the fertilizer credit scheme on the farm productivity and welfare of the farmers. Fortunately, there are large variations in the use of credit access across regions and over time, and such variations provide an opportunity to evaluate the effects of the credit scheme on crop production and income using panel data.¹

The purpose of this chapter, therefore, is to evaluate the impact of the credit scheme on the inorganic fertilizer application, the crop yields, and the crop income by using a 2-year panel data of 420 households in rural Ethiopia. The major obstacle to identifying a causal impact of a credit scheme is that farmers voluntarily participate in such schemes rather than being randomly assigned. To overcome or mitigate the possible self-selection biases, we take advantage of the panel data by controlling for unobserved household characteristics. The results in this chapter suggest that the credit increases inorganic fertilizer use per hectare but has only limited impacts on crop yields. The limited impacts are likely due to low adoption rates of high-yielding varieties, which should ideally accompany with the inorganic fertilizer use. We find that only about 10% of our sampled farmers cultivate high-yielding maize or wheat varieties, while others apply the inorganic fertilizer on local varieties of maize and wheat. As a result, the credit has little impacts on crop income.

This paper is organized as follows: Sect. 4.2 explains the changes in inorganic fertilizer policies in Ethiopia and its current situation. Section 4.3 describes the household survey data used for this study. Section 4.4 presents the empirical findings on the effect of the provision of input credit on inorganic fertilizer application, crop yield, and income. Finally, we discuss the policy implications based on the results we obtained.

¹It is worth noting that the inputs provided by regional governments or cooperatives on credit are highly subsidized and, hence, they can provide those inputs at very low or even zero interest rate. Because of the high inflation rate in Ethiopia, the low interest rate means that the real interest rate is negative. Hence, "the input credit" has two different effects. The first is the effect of easing credit constraints by obtaining the credit for the purchase of the inputs. The second is the effect through the change in relative prices of the inputs. In this paper, the effect of "the input credit" means the mixed effect of those two components.

4.2 Fertilizer and Credit Policies in Ethiopia

Even when new technologies appear to be very profitable to crop scientists and economists, farmers may not adopt them (Feder et al. 1985; Munshi 2007; Duflo et al. 2008). One of major constraints for small-scale farmers to adopt agricultural technologies is credit (e.g., Croppenstedt et al. 2003; Gine and Klonner 2006; Zerfu and Larson 2010) since cash resources are generally insufficient to cover high-yielding variety seeds and chemical fertilizer purchase for small-scale farmers at the planting season. Despite the importance of credit, the private financial sector is underdeveloped, especially in rural areas due to high and correlated risks in small-holder agriculture, asymmetric information between borrower farmers and credit providers as well as incomplete enforcement of credit contracts. Thus, public intervention to credit market has been justified for the purpose of improving formal credit access of small-scale farmers. In spite of the potential of public intervention in financial services for small-scale farmers, however, such an intervention has to be considered with caution because there are some drawbacks. First, it may crowd out private financial service providers that would be more efficient than public providers. Second, a certain type of public intervention such as agricultural lending and input credit is often used as an instrument of political capture and, hence, persistently continued even when it does not have measurable impact on agricultural output.²

Historically in Ethiopia, a government parastatal called Agricultural Input Supply Enterprise (AISE) controlled the importation, distribution, and pricing of inorganic fertilizer during the Dergue regime (1974–1987). The Ethiopian government began curtailing the operation of the official state marketing board under foreign aid – conditionality agreements with donors since 1993. The private sector was allowed to participate in fertilizer importation and distribution following the issuance of the National Fertilizer Policy (Jayne et al. 2003). As a result, some private companies entered into the sector. The government, however, gave favorable treatments toward regional holding companies, which competed with the private companies. The favorable treatments included the allocation of foreign exchanges for the importation and distribution of fertilizer through government-administered credit to farmers. Because of these favorable treatments toward regional holding companies, private companies found it impossible to compete with them, and all of the private companies exited from the market by 2000. Since then, the distribution system of inorganic fertilizer has been dominated by AISE and a small number of the regional holding companies (Spielman et al. 2010).

In recent years, under the SDPRP and the PASDEP, the government has started providing substantial resources to the regional governments to enhance agricultural production. To attain several goals of the PASDEP, the government has been restructuring and strengthening cooperatives. Corresponding to the government

²Conning and Udry (2007) provide a comprehensive review of financial sector in rural areas of low-income countries.

action, the number of members participating in cooperatives has increased rapidly, and hence the cooperatives have gained more power than before. Since 2004, several cooperative unions have started to operate in the distribution of agricultural inputs at the regional level. The farmers' cooperatives have replaced the AISE in the importation and distribution of fertilizer. The cooperatives currently provide about 56% of the total supply of fertilizer. The cooperatives provide short-term credit on fertilizer purchases to farmers under a 100% credit guarantee scheme by the regional governments. The largest source of such agricultural credit is the Commercial Bank of Ethiopia (CBE) serving more than 2.5 million farmers. As of 2006, two regional holding companies (Ambassel and Wondo), the fertilizer parastatal (AISE), and cooperative unions accounted for 100% of fertilizer imports and local distributions.

Partly due to the credit scheme, as mentioned earlier, the total fertilizer consumption in Ethiopia has increased from 250,000 tons in 1995 to 400,000 tons in 2008 (Spielman et al. 2010). However, the intensity of the fertilizer use has increased only marginally over the past decade from 31 kg/ha in 1995 to 36 kg/ha in 2008. The increase in the total fertilizer consumption has been absorbed largely by area expansion. Moreover, despite the huge PASDEP demonstration programs, only 37% of farmers were using inorganic fertilizer (Spielman et al. 2010). A study cited in Spielman et al. (2010) found that half of the farmers surveyed for the study reported that the fertilizer arrived after planting. It also found that 32% of the surveyed farmers reported underweight bags, and 25% complained of the poor quality. Also, unlike neighboring countries such as Kenya, Ethiopia does not offer fertilizer in smaller packages that could be used by smallholders or in different formulations needed for different types of agro-climates, soils, and crops. Thus, the application of standard packages to vastly diverse environments in Ethiopia and the nonoptimal use of these packages by farmers lead to low fertilizer production efficiency and returns to investment. Much of the discussion on the effects of the fertilizer credit production efficiency, however, is based on secondary macro data or from small cross-sectional case studies. There is a need for a rigorous impact study that is based on a wide area, which relies on individual panel data set. Panel data enables one by which we can observe the changing behaviors of the same farm households with and without fertilizer credit. The drastic changes in the distributions of inorganic fertilizer in recent years create substantial variations across regions in access to input credit. Such variations provide us an opportunity to evaluate the effect of the input credit on input use, crop yields, and farmers' welfare in Ethiopia.

4.3 Data and Descriptive Statistics

4.3.1 Data

The data used in this paper have been collected through the RePEAT household survey in rural Ethiopia by the FASID/GRIPS research team in 2004 and 2006. The survey covers 42 villages in 11 zones located within a 400 km radius from

Table 4.1 Characteristics of sample households

	Number of households	Proportions of households that used fertilizer		Proportions of fertilizer users who obtained credit		Inorganic fertilizer use per ha (kg/ha)	
		2004	2006	2004	2006	2004	2006
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Amhara	39	0.33	0.46	0.10	0.18	16.6	29.9
<i>Oromia Oromiya</i>							
South east	48	0.83	0.90	0.61	0.90	58.7	67.8
Central	134	0.91	0.91	0.77	0.86	120.8	108.9
West	30	0.47	0.53	0.47	0.47	20.1	24.3
SNNP	157	0.73	0.65	0.22	0.48	55.6	56.1
Total	408	0.75	0.74	0.46	0.63	71.0	69.8

Addis Ababa. In each village, 10 households were randomly selected in 2004 and reinterviewed in 2006.³ All the households in the survey engage in agriculture. The survey villages belong to three regions; Amhara, Oromia, and SNNP. Out of the 42 survey villages, 21 are located in Oromia, which is the largest region surrounding Addis Ababa and has several different agroecological zones. Hence, we divide the Oromia region into three subregions (SoutheastSouth East, Central, and West) with consideration of the differences in their farming systems for the following analyses. We present the summary statistics of the sample households by region in Table 4.1.

The proportion of households using inorganic fertilizer varies from 33% in the Amhara region to 91% in Oromia Central. On average, about two-thirds of the sample households applied at least some inorganic fertilizer. This is a high proportion by African standards. The main reason for the high inorganic fertilizer use is the credit that farmers receive. In Table 4.1, we find that about 46% of the sample farmers received credit in 2004, and that the proportion increased to 63% in 2006. The southeast and central regions of Oromia have high proportions of farmers receiving credit. This is likely to reflect the high intensities of government investment and effort in delivering public interventions on input credit by the regional government. Partly because of the credit programs in these locations, the amounts of inorganic fertilizer applied on crop production are very high in these subregions. The amount of inorganic fertilizer applied is about 121 kg/ha in 2004 and 109 kg/ha in 2006 in the southeast region of Oromia and is 59 and 68 kg/ha in the West region. In contrast, in the Amhara region, where only less than 20% of the sample households received credit in 2004 and 2006, the level of inorganic fertilizer application is at the lowest among the sample regions. Thus, it appears that the credit access has significant impacts on the use and amount of fertilizer application.

³In the following analyses, 12 out of 420 households are dropped due to missing information on variables of interest in the 2004 data while 9 households are dropped due to attrition in the 2006 survey.

We need to be cautious about the causal relationship between the credit and fertilizer use because it is possible that the causality goes the other direction. The provision of credit by the regional credit programs might be provided in regions where fertilizer use is high even without the credit.

4.3.2 Descriptive Statistics

To identify the causal relationship between credit and fertilizer use, we divide the samples into four groups based on their access to credit: non recipients, late recipients, early recipients, and continuous recipients. Non recipients include households that did not obtain credit in both 2004 and 2006. Late recipients include households that did not obtain credit in 2004 but obtained it in 2006. In contrast, early recipients include households that obtained credit in 2004 but did not in 2006. Finally, continuous recipient includes households that obtained credit in both 2004 and 2006. The examination of the fertilizer applications of these groups may indicate how much fertilizer use changes when the credit access changes over time at the household level.

In Table 4.2, we find that, among the late recipients group, the fertilizer application increases by 37 kg/ha, from 54 kg/ha in 2004 to 91 kg/ha in 2006, when they gained access to credit in 2006. The change is statistically significant at the 1% level. Furthermore, since there is a downward trend in the fertilizer use over the years among sample households, the ‘true’ effect could be larger than 37 kg/ha among the late recipient households. On the other hand, among the early recipients group, we find a decrease in fertilizer application by 19 kg/ha, as they lost their access to credit from 2004 to 2006. Among the other two groups, non recipients and continuous recipients, we find slight declines in fertilizer applications. Thus, it seems that there is a downward trend in the fertilizer use over the years among sample households. This suggests that, in the absence of fertilizer used by continuous recipients is several times the amount used by non recipients. The real causal

Table 4.2 Inorganic fertilizer use (kg/ha) by access to credit

	Access to credit in 2004 and 2006				
	All	Non recipients	Late recipients (received credit only in 2004)	Early recipients (received credit only in 2006)	Continuous recipients
	(1)	(2)	(3)	(4)	(5)
<i>Fertilizer use (kg/ha)</i>					
In 2004	72.6	28.0	54.3	88.1	114.6
In 2006	70.0	17.7	90.8	69.0	96.2
Change: 2006–2004	–2.7	–10.3	36.5***	–19.1	–18.5
Number of households	408	126	96	28	158

*** Significant at 1% on the *t*-test for the difference in mean

Table 4.3 Crop choice (% of households) in 2004 and 2006 by credit access

	Access to credit in 2004 and 2006				
	All	Non recipients	Late recipients (received credit only in 2004)	Early recipients (received credit only in 2006)	Continuous recipients
	(1)	(2)	(3)	(4)	(5)
<i>Teff</i>					
2004	0.43	0.26	0.41	0.58	0.54
2005	0.51	0.28	0.50	0.48	0.71
<i>HYV maize</i>					
2004	0.07	0.05	0.06	0.19	0.07
2005	0.09	0.08	0.17	0.04	0.07
<i>Local maize</i>					
2004	0.36	0.47	0.41	0.12	0.29
2005	0.35	0.47	0.29	0.19	0.31
<i>HYV wheat</i>					
2004	0.11	0.04	0.13	0.15	0.14
2005	0.09	0.04	0.12	0.11	0.12
<i>Local wheat</i>					
2004	0.40	0.21	0.44	0.39	0.52
2005	0.37	0.14	0.38	0.44	0.54
Number of households	408	126	96	28	158

impact of these support the hypothesis that credit is very important for fertilizer purchase and use of the credit access could be larger than the 37 kg/ha among the enter households.

To investigate the impacts of the credit program on crop yields, we first look at the crop choice of the farmers with and without credit. In Table 4.3, we present the crop choice in 2004 and 2006 grouped by the credit status, as in Table 4.2. What should be noted in this table is that proportions of farmers who cultivate high-yielding varieties (HYV) are very low in Ethiopia. For instance, the proportion of the sample farmers who cultivate HYV maize is only 7% and 9% in 2004 and 2006, respectively. Likewise, the proportion of the sampled farmers who cultivate HYV wheat is only 11% and 9% in 2004 and 2006, respectively. Even when we disaggregate the sampled farmers by the credit access status, we do not find a high proportion of HYV adopters among those who received credit. For instance, only 7% of continuous recipients cultivated HYV maize in both 2004 and 2006. Among the same continuous recipients, we find that about 30% of them cultivate local maize. Thus, among maize producers in this group, only 20% of them cultivate HYV maize. Among late recipient households who did not receive credit in 2004 but received it in 2006, we find an increase in the proportion of those who cultivate HYV maize from 6% in 2004 to 17% in 2006 and a decline in the proportion of those who cultivated local maize from 41% in 2004 to 29% in 2006. Thus, it seems

that the HYV maize adoption rate responds to the availability of the fertilizer credit to some extent among this group, although the proportion of the maize producers who adopt HYV maize is only 37% even among this group in 2006, when they receive the credit.

In contrast, the HYV adoption rate does not respond to the availability of the fertilizer credit among wheat producers. Among the Late Recipient group, the proportion of the farmers who adopt HYV wheat is 13% before receiving the credit and just at 12% even when they receive the credit. Among the same group, about 40% of the farmers produce local wheat, thus the HYV wheat adoption rate remains about 22%. With low adoption rates of HYV of maize and wheat, it is unlikely that the fertilizer credit program would have large impacts on the crop yields because local varieties have low response rates to fertilizer use in general.

To examine the impacts of the credit on the crop yields, we present the average yields of major cereal crops by the credit used or accessed in Table 4.4. In the table, we find that the average yields of teff and local wheat are higher when the credit is available than it is not available. The overall average of the teff yield is 665 kg/ha. It is 553 kg/ha when credit is not available, while it increases to 704 kg per ha when credit is available. The difference of these two is about 151 kg/ha, which is a 27% increase. The credit also increases the average yield of local wheat from 808 kg/ha to 1,072 kg/ha. The increase is about 264 kg/ha, which is a 33% increase. Thus, it seems that the credit access increases the yields of teff and local wheat, although the average yields of these crops with credit are still at a very low level by international standards. The credit, however, is expected to increase the yields of HYV varieties to a greater extent because the credit increases the inorganic fertilizer application on the HYV varieties, which are much more fertilizer responsive. Indeed, we find higher yields on HYV maize and wheat when the credit is available than when it is not available, in Table 4.4, although differences in the yields are

Table 4.4 Crop yields and credit access

Crop	All (1)	Access to credit		Difference (3)–(2) (4)
		Without credit (2)	With credit (3)	
Teff	664.9 (445.7)	553.2 (396.2)	704.4 (455.8)	+151.2*** [40.6]
HYV maize	1,800.6 (1,382.7)	1,714.5 (1,550.4)	1,838.3 (1,318.5)	+123.8 [364.1]
Local maize	1,233.3 (1,060.9)	1,309.3 (1,149.8)	1,130.1 (920.5)	–179.2 [115.8]
HYV wheat	1,144.5 (769.1)	1,080.6 (872.3)	1,170.1 (730.1)	+89.5 [186.6]
Local wheat	998.1 (794.7)	807.5 (664.0)	1,071.6 (828.9)	+264.0*** [78.8]

Numbers in parentheses are standard deviations, and numbers in brackets are standard errors

*** Significant at 1% on the *t*-test for the difference in mean

small in magnitude and statistically insignificant. The weak impacts of the credit on the average yields of these HYV crops suggest some problems with the HYV varieties, such as unsuitability to the particular site, inappropriate application of inorganic fertilizer on the HYV varieties, or poor quality of these HYV seeds. To confirm and further understand these findings, we need a more rigorous approach. In the following sections, we use regression models in which we can control external factors such as agroecological conditions and farmer characteristics in addition to the credit availability of credit.

4.4 Empirical Models and Variables

The main purpose of this chapter is to identify the impacts of the credit access to public sector fertilizer credit on the inorganic fertilizer application, yields, and income. We use a binary indicator representing whether a household obtains the input credit in each of the 2 years. The major issue on estimating such impacts is the endogeneity of the credit access variable. Households that receive credit may have different characteristics than those who do not receive credit. Those who receive credit may be more capable or located in more fertile areas than those who do not receive credit. This can create a spurious correlation between the credit use and the crop yields or income. To overcome this issue, we employ the difference-in-differences approach with time-variant control variables. The basic empirical model can be written as a simple regression form:

$$y_{ijt} = \alpha d_{ijt} + \beta x_{ijt} + \delta_i + v_{jt} + \varepsilon_{ijt}, \quad (4.1)$$

where y_{ijt} is the yield or the income of household i in region j at time t ; d_{ijt} is a dummy variable taking 1 if household i received the credit at time t ; x_{ijt} is a vector of household characteristics; δ_i is a time-invariant household component, which represents unobserved household characteristics; v_{jt} is a time-variant region component; ε_{ijt} is household-specific transitory shock that has mean zero at each time t . Our focus is to estimate the coefficient of the credit dummy, that is, α . By estimating the household fixed effects model, we can eliminate the time-invariant household component, δ_i , which could be correlated with the independent variables including the credit dummy, d_{ijt} .

One drawback of the household fixed effects model is that all of the time-invariant household characteristics would be excluded from the model, along with δ_i . Thus, we are unable to estimate the coefficients of some of the important household characteristics, such as the education level and the gender of the household head, and the soil fertility because we have only one time observation of the soil fertility. Despite the drawback, however, we prefer estimating the household fixed-effects model because our purpose is to identify the impacts of the input credit program on the agricultural productivity and income.

4.5 Results

4.5.1 Determinants of Use of Access to Fertilizer Credit

We estimate the determinants of the access to fertilizer credit and present the results in Table 4.5. Household characteristics and household head's characteristics are included as the covariates. The results are obtained from the conditional logit estimation method. Thus, the identification of the parameters of interest relies on within-village variation. The result shows that the land size has a positive and significant impact on the credit access but the value of asset holdings does not have a significant impact. It appears that cooperatives and public banks provide the fertilizer credit based on the needs of the recipients, represented by land size, but not based on the repayment ability of the recipients, because if they are concerned with the repayment ability, the value of asset holdings should have a significant impact on the credit access. In addition, the cooperatives and public banks do not seem to be gender neutral, judging from the negative and significant coefficient of female-headed household dummy, which indicates that female-headed households are less likely to receive the fertilizer credit than male-headed households.

Table 4.5 Determinants of access to input credit (village FE model^a)

	Received credit (=1)
Log of land size (ha)	0.745 (2.05)**
Log of asset holdings (Birr)	0.162 (1.40)
Number of cattle	-0.013 (0.71)
Log of soil carbon content	-0.740 (0.99)
1 if female-headed household	-0.821 (2.46)**
Number of family members	0.068 (1.35)
Dependent ratio ^b	0.055 (0.10)
Household head's years of schooling	-0.005 (0.12)
Household head's age	0.001 (0.15)
Interaction terms between region and survey year dummies	Included
Observations	537
Number of groups (year*village)	57

Absolute value of z scores in parentheses

** Significant at 5%

^a Conditional logit estimation with village*year fixed effects

^b Fraction of household members aged 0–15 or over 65

4.5.2 Impacts on the Fertilizer Application

Next, in Table 4.6, we present the results from the household fixed-effects models on the quantity of inorganic fertilizer application. The results are very similar to what we find in Table 4.2. In fact, when we estimate a simple model with the credit dummy variable and dummies for regions, survey years, and interaction terms between them, column (1), we find that the impact of the credit is 36 kg/ha, which is almost identical to the increase in fertilizer use among the late recipient group, 36.5 kg/ha, in Table 4.2. The estimated coefficient of the credit variable remains at the same level, 35.1 kg/ha, even when we add some time-varying household characteristics to the model. Because the average fertilizer application level is about 70 kg/ha, according to Table 4.2, a 35 kg/ha increase is a 49% increase in the amount application. Because we include interaction terms of regions and survey years in the model, it is unlikely that the unobserved regional level shocks are correlated with the credit variable, thereby generating biased estimators.

The estimated coefficients of the other independent variables are consistent with our expectations. Land size has a negative coefficient on the quantity of inorganic fertilizer used per ha, indicating that inorganic fertilizer is more intensely applied among small landholders than large landholders. The size of the estimated coefficient indicates that the inorganic fertilizer application increases by 0.46 kg when the land size decreases by 1%. Asset holding also has a significant impact on the inorganic fertilizer application: a 1% increase in the asset holding increases the inorganic fertilizer application by 0.16 kg/ha. Thus, even when credit is available, the asset holding matters on the inorganic fertilizer application. This suggests that at least

Table 4.6 Determinants of inorganic fertilizer application (household FE models)

	Inorganic fertilizer application (kg/ha)	
	(1)	(2)
Credit (=1)	36.01 (2.76)***	35.07 (2.62)***
Log of land size (ha)		−45.96 (4.37)***
Log of asset holdings (Birr)		15.84 (3.75)***
Number of cattle		0.367 (1.18)
Number of family members		−4.957 (1.73)*
Interaction terms between region and survey year dummies	Included	Included
Observations	782	773
Number of households	402	402
R-squared	0.05	0.13

Absolute value of *t* statistics in parentheses
* Significant at 10%, *** significant at 1%

some households are still facing credit constraints and that access to cash on hand determines how much fertilizer they apply on crops. Finally, we find that the number of family members has a negative coefficient on the fertilizer application, suggesting that the family workers and the inorganic fertilizer are substitutes. One additional family worker replaces about 5 kg of inorganic fertilizer per ha.

4.5.3 Impacts on Crop Yields and Income

To measure the impact of the credit access on crop yields, we estimate the yield functions of three major crops, teff, maize, and wheat, in our survey areas with the household fixed-effects model (Table 4.7). The results indicate that the credit access has a significant impact on teff but not on maize and wheat. The estimated coefficient of the credit is 0.37 on teff, suggesting that the teff yield increases by 37% if credit is provided. This increase is due to the increased inorganic fertilizer use as we found earlier. On the maize and wheat yields, we do not find any significant impacts. As we can see in Chap. 3 in this book, the farm-gate price of teff is much higher than the farm-gate prices of maize and wheat: the farm-gate price of teff is \$22.6 and 32.6 per 100 kg in 2004 and 2006, respectively, while the farm-gate price is \$10.9 and 13.0 for maize and is \$14.0 and 20.8 for wheat in 2004 and 2006, respectively. Thus, it seems more profitable to apply inorganic fertilizer on teff than on maize or wheat.

Table 4.7 Crop yield (kg/ha in log) models (household FE models)

	Teff	Maize	Wheat
	(1)	(2)	(3)
Credit (=1)	0.369 (2.89)**	0.393 (1.41)	0.136 (1.09)
Log of land size (ha)	0.032 (0.16)	0.355 (0.96)	-0.058 (0.29)
Log of asset holdings (Birr)	-0.005 (0.08)	-0.102 (0.96)	-0.028 (0.38)
Number of cattle	0.006 (1.43)	0.008 (0.46)	-0.000 (0.09)
Number of family members	-0.089 (1.65)	-0.051 (0.65)	-0.066 (1.37)
Constant	7.086 (7.75)**	7.003 (4.96)**	7.205 (8.66)**
Interaction terms between region and survey year dummies			
Observations	Included 582	Included 385	Included 565
Number of household ID	229	214	230
R-squared	0.11	0.09	0.06

Absolute value of robust *t* statistics in parentheses

** Significant at 5%

Table 4.8 Crop income models (household FE models)

	Log (crop income per ha)
	(1)
Credit (=1)	−0.037 (0.35)
Log of land size (ha)	−0.845 (4.81)***
Log of asset holdings (Birr)	0.101 (1.83)*
Number of cattle	0.000 (0.03)
Number of family members	−0.034 (0.70)
Constant	7.629 (12.99)***
Interaction terms between region and survey year dummies	Included
Observations	755
Number of household id	398
R-squared	0.18

Absolute value of robust *t* statistics in parentheses

* Significant at 10%, *** significant at 1%

Regarding the impact of the credit on income, we present the results on the crop income per ha in Table 4.8. In the table, we find no impact of the credit on income: the estimated coefficient of the credit on the crop income per ha is -0.037 and the *t*-statistics is not even close to a significant level. The crop income is calculated by subtracting the input cost, which includes the costs of credit, fertilizer, other chemicals, and hired labor, from the value of crop production. The value of crop production is the sum of the values, evaluated at the market prices, of all crops. Because the credit access increases the yield of teff by 37% among the sample households, it should also increase the total value of crop production to some extent. However, the increased yields come with increased costs of fertilizer, which are covered by the credit repayment. Thus, it seems that the cost of fertilizer largely offsets the increased revenue.

4.6 Conclusions

In this chapter, we evaluate the impact of the fertilizer credit on input use for crop production, crop choice, crop yield, and household income using a 2-year panel data set of 420 households in rural Ethiopia. We find that the credit access increases inorganic fertilizer use by 35 kg per household. We also find that the credit access increases the yield of teff by 37% but not the other major crops, such as maize and wheat. The lack of impact on maize and wheat is predictable given the low adoption rates of HYV of maize and wheat, even among those households that receive the

fertilizer credit. Only 20% of the maize producers adopt the HYV of maize, and the adoption rate is about the same among wheat producers. Without fertilizer-responsive HYV, the fertilizer credit program can have only limited impacts on the crop yields and, hence, the farmers' incomes. Thus, consistent with Hypothesis 2 postulated in Chap. 1, Ethiopian farmers do respond to the availability of fertilizer credit through the government program by applying more fertilizer and producing more profitable crops, but the credit program has no significant impacts on net crop income per cultivated area and the per capita income.

The results raise a concern about the effectiveness of the credit program in Ethiopia in improving the living conditions of the farmers. First, the government must facilitate the development of private fertilizer markets by reducing the government intervention in order to reduce the inefficient fertilizer delivery and poor fertilizer quality problems. Second, low responses to the fertilizer credit on crop yields should be addressed by the government. In the short term, to improve the returns to the credit program, the Ethiopian government needs to consider providing HYV to farmers, along with the fertilizer credit. In particular, drought-tolerant varieties should be provided because Ethiopian farmers suffer from frequent droughts in the country. Because the drought-tolerant varieties are still new in the country, there is a need to conduct adoptive research on the new varieties so that the varieties will fit better with the local conditions. Furthermore, extension services should accompany the provisions of these materials. Without such complementary materials and services, the fertilizer credit program will have only limited impacts on farmers' welfare, and it would be difficult to continue operating such an expensive program without more tangible returns.

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Chapter 5

Emerging Markets in the Post-liberalization Period: Evidence from the Raw Milk Market in Rural Kenya

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Abstract This chapter examines how the raw milk market in western and central Kenya has developed after the dairy sector liberalization in 1992 by using panel data of 862 rural households. From the late 1990s to 2004, the proportion of households that sold milk to traders more than doubled, while it declined from 29% to 12% for those who sold milk to dairy cooperatives. To examine this change in the milk market, we use the price differentials between the farm gate and retail prices as a proxy for the functioning of the market. Our empirical analyses clearly show that the functioning of the market improved between the late 1990s and 2004.

Keywords Milk market • Market liberalization • Market efficiency • Agricultural policy • Kenya

5.1 Introduction

The outcomes of the structural adjustment programs implemented in the 1980s and 1990s in many African countries have been mixed. Some studies find improved efficiency after the structural adjustment programs as evidenced by the increasing

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entry of traders (Barrett 1997) and improved market integration (Badiane and Shively 1998). However, others find that markets remain inefficient even after the introduction of the structural programs (Lutz et al. 2006; Negassa et al. 2004; Fafchamps 2004; Poulton et al. 1998). One explanation for these mixed results is that, in many countries, the liberalization policies were only partially implemented and policy reversals were common (Jayne et al. 2002; Kherallah et al. 2000). Thus, it has been difficult to evaluate market reform programs that were never fully implemented. Another explanation, which is closely related to the present study, is that policy makers and donor agencies did not fully recognize the immaturity of the market institutions in the countries that adopted the programs (Dollar and Svensson 2000) and had unrealistic expectations that markets would develop soon after the removal of the market controls (Staal et al. 1997).

In this chapter, we take the case of the milk industry in Kenya where private traders have gradually entered the marketing business since the market liberalization. Before the liberalization, the formal milk market was monopolized by a parastatal processing company, namely Kenya Cooperative Creamery (KCC), which coordinated supply chains through dairy cooperatives. Just after the collapse of KCC in 1998, the formal dairy sector in Kenya experienced a slump and many dairy farmers were without milk buyers. Since raw milk is highly perishable and requires careful management to maintain the quality, the long-distance transportation of raw milk by private traders was not common before the liberalization. Only after several years of a liberalized market were private traders able to develop their own marketing channel and ensure adequate quality control, which made it possible to trade raw milk over a long distance.

The objectives of the chapter, therefore, is to examine the effects of the change in the market structure on the milk price and on the price spread between the farm gate and retail prices. Since milk producers are net sellers of milk, an increase in the milk producer price can improve farmers' welfare by increasing the income from milk sales. However, whether the liberalization of the milk market in Kenya has increased the producer price remains unclear since the milk price had been influenced by the government and often cross-subsidized across locations and time. Therefore, it is important to examine this issue in detail. If the liberalized milk market has resulted in more competitive milk trading, the price spread is expected to shrink after the liberalization.

The rest of the chapter is structured as follows. In Sect. 5.2, we explain the specific hypothesis and empirical models used to examine the changes in milk marketing costs. Section 5.3 presents the panel data used in the study and examines how the sample households have changed their milk marketing. In Sect. 5.4, we empirically test our hypothesis and discuss the regression results. Section 5.5 provides the conclusions and policy implications.

5.2 Empirical Models and Hypotheses

5.2.1 Market Efficiency and Price Analyses

The post-liberalization period of the milk market in Kenya provides an interesting opportunity to investigate the relationship between market structure and its efficiency.¹ Just after the liberalization and the collapse of KCC, we suppose that marketing costs were high in the milk market. This is because dairy farmers had to search for new milk buyers, and inexperienced traders did not know how to keep milk unspoiled or where to sell their milk. In addition, marketing institutions, such as marketing channels and the long-term relationships between buyers and sellers, had to be developed over time. Thus, we speculate that as traders gained experience, untrustworthy traders were weeded out, and marketing institutions were developed, after which marketing costs have been reduced. Thus, we propose the following hypothesis:

Hypothesis 5.1

The functioning of the milk market has improved as the role of private traders has become more important in the milk marketing business, thus lowering the milk marketing costs.

To test Hypothesis 5.1, we propose the following strategy. Consider a simple raw milk market, where raw milk is sold at a kiosk at retail price, P_t^R , at time t . For simplicity, we assume that the kiosk buys milk from private traders at the same price. Traders collect the milk from dairy farmers at farm gate price, P_t^F , at time t . Dairy farmers pay for the transportation costs when they sell milk at a kiosk for a retail price, P_t^R , while traders pay for the transportation cost when they buy milk at a farm gate for a farm-gate price, P_t^F . The price spread between the retail and farm-gate prices is used as a proxy of the marketing costs, which consist of measurable costs and immeasurable transaction costs. Hypothesis 5.1 is formalized as

$$H_0 : (P_2^R - P_2^F) - (P_1^R - P_1^F) = C_2 - C_1 = \delta < 0, \quad (5.1)$$

where $t=1$ and 2 indicate the first and second round of the panel data, respectively.

Since other factors such as traveling time to urban center and community-level unobserved heterogeneity may affect the change in price differences between retail

¹Please find a detailed description of the market liberalization of the dairy market in Kenya in the next chapter (Chap. 6).

and farm-gate prices, we conduct regression analyses for testing the hypothesis. The method we apply is to estimate the difference-in-difference (DID) estimator, δ . The DID estimator is estimated by running the following model:

$$P_{it} = \beta_0 + \beta_D D_{it}^R + \delta(D_{it}^R \times T) + \beta_T T + \beta_g g(d_i) + \beta_{gT}(g(d_i) \times T) + v_j + e_{it}, \quad (5.2)$$

where P_{it} is the milk price paid to dairy farmer i either at the retail shops or at the farm gate²; D_{it}^R is a dummy variable for the retail price, which takes one if the milk price is paid at the retail shops; T is the number of years since the 1st wave, which is zero for the first-wave observations; $g(d_i)$ is a function of the traveling time from household i to the nearest urban town; and v_j represents the community fixed effects. As we explain in the next section, we use three separate but comparable surveys in the late 1990s as a first wave of panel data used in this paper. In 2004, a follow-up survey was conducted on subsamples of the three surveys in the first wave. To control for different lengths between the first and second waves, we include T in the estimation model. The coefficients, β and δ , are to be estimated.

From Eq. 5.2, the change in price differentials, the differences in retail and farm-gate prices, over time is written as

$$(P_2^R - P_2^F) - (P_1^R - P_1^F) = (\beta_0 + \beta_D + \delta + \beta_T) - (\beta_0 + \beta_T) - (\beta_0 + \beta_D) + \beta_0 = \delta.$$

This shows, therefore, that the coefficient of the interaction term between D_{it}^R and T is the DID estimator (δ) and captures the change in marketing costs as explained in Eq. 5.1. According to Hypothesis 5.1, δ is negative, suggesting that the price spread between the farm gate and retail prices, which is a proxy for the marketing costs, has been reduced in recent years. Although we think that the price spread between the retail and farm-gate prices is a reasonable proxy for the marketing costs, the lack of explicit measures of the marketing costs, which could potentially be available from a milk trader survey, remains as one of the major constraints in the present study.

² We define the “retail price” as the price that a milk producer receives at a retail shop after transporting the milk to the shop and the “farm-gate price” as the price that a milk producer receives at his or her farm gate. The “retail price” in an area should be uniform if the milk is sold at shops in a well-integrated market at the same time. However, our respondents sold milk at different dates even within a given season (rainy or dry season) and at different retail shops that may be located in different market centers. In addition, the price offered by the potential buyers could be different across milk producers because of negotiation skills and quantity supplied (Baltenweck and Staal 2007). Therefore, it is possible for the price variable to have subscript i . The transportation costs and other marketing costs are not included in the “farm-gate price.”

5.3 Data and Sample Households

5.3.1 Data

We use panel data of 862 households in rural Kenya. The survey in the first round was conducted in the late 1990s by the Smallholder Dairy Project (SDP, 2004), a collaborative team from the Ministry of Livestock Development & Fisheries, the Kenya Agricultural Research Institute, and the International Livestock Research Institute. In 1996, SDP first conducted a survey of 334 rural households in Kiambu District (Central Province) near Nairobi. Then, in 1998, the survey was expanded to eight districts in the Central Kenya region, and covered 1,390 additional households (Staal et al. 2001). In 2000, 1,576 households from seven districts in the Western Kenya region were interviewed (Waithaka et al. 2002). A total of 3,300 rural households were randomly selected according to a sampling procedure that randomly selects households along transects connecting randomly selected landmarks in each sample community. Thus, the first round of the panel data comprises a series of three household surveys collected in 1996, 1998, or 2000. For ease of presentation, we denote this round as “the 1998 data” hereafter.

In 2004, as part of the Research on Poverty and Environment and Agricultural Technology (RePEAT) Project, 100 sub-locations (the smallest administrative unit in Kenya) were randomly selected from sub-locations where the SDP households resided.³ In each sub-location, ten SDP households were randomly selected for reinterviews.⁴ In the 2004 RePEAT survey, households were asked about their agricultural and nonagricultural income-generating activities, asset holdings, cash expenditure, and demographic characteristics. Although new questions were added in the 2004 RePEAT survey, most of the questions on livestock and dairy production were kept comparable with the SDP surveys. Thus, the panel data can be used for measuring changes in milk marketing between 1998 and 2004. Note that these periods do not cover the era prior to the liberalization. This study does not aim to evaluate the effect of the liberalization by comparing the situations before and after the liberalization. Rather, we attempt to understand how markets have developed by looking at the changes in the post-liberalization period.

³The RePEAT Project is a collaborative research project of Foundation for Advanced Studies on International Development, National Graduate Research Institute for Policy Studies, the World Agroforestry Center, and Tegemeo Institute in Kenya. More details on RePEAT are available in Yamano et al. (2005).

⁴Out of the 1,000 targeted households, 914 households were successfully identified and 874 households were interviewed in 2004. The rest (40 households) were successfully found but not available for interview due to several reasons: noncontact (27 cases), moved away (6 cases), refusal (5 cases), nonavailable (1 case), and households dissolved (1 case). Among the 874 households, we do not use 12 households since some of the variables used in the analyses are missing.

5.3.2 Sample Households and Changes in Milk Production and Marketing

We present the number of sample households, the per capita income, the milk income share, the size of land owned, the number of cows, and the proportion of milk-producing households that raise cows in zero-grazing units in 2004 by province in Table 5.1. The sample households tend to own small plots of land, and it is common for households to depend both on crop and livestock production. Because of population pressure, the shift of livestock production from grazing local cattle to zero-grazing improved cows is observed in most locations. Income from milk production accounts for about 20% of total household income in Central Province and Rift Valley Province, while it is only 2.6% and 7.4% in Western and Nyanza Provinces, respectively. The high milk income share in the Central and Rift Valley Provinces is partly because households in these provinces raise improved cows, which produce much more milk than local cows, in zero-grazing units.

Table 5.2 shows how the adoption of improved cows changed between 1998 and 2004. This transition matrix indicates that the number of households adopting improved cows increased significantly from 209 to 503 in this period. It is important to note that 25% of the households that had improved cows in 1998 did not own improved cows in 2004. This means that the adoption of improved cows is not a one-time decision but a time-variant decision. An important question is what determines the change in the number of improved cows adopted.

It is possible that differences in infrastructure affect the adoption of improved cows. As measures of supportive milk production infrastructure, we use the number of providers of veterinary services, artificial insemination (A.I.) services, and Tsetse control services operating at the time of the first and second rounds in the sample sub-locations in Table 5.3. In most of the sample sub-locations, at least one veterinary service provider is available. Between 1998 and 2004, the number of service providers increased especially in the Central and Western Provinces. Even though the number of improved cows is the lowest in the Western regions (Table 5.1), the number of A.I. service providers is the highest. Thus, there is no clear positive association between the adoption of improved cows and the availability of service providers.

5.3.3 Milk Price and Marketing Costs

Table 5.4 shows the change in the raw milk price and marketing costs by traveling time to urban towns.⁵ In this study, we measure the raw milk price by the sales revenue of the milk producers divided by the quantity sold. This method does not

⁵ All price levels are adjusted to the 2004 price level with the price index in the Statistical Bulletin (Central Bank of Kenya, June 2002, 2004, and 2005).

Table 5.1 Sample households in the REPEAT survey (2004)

Province	Number of households (A)	Distance to Nairobi (km) (B)	Per capita land owned (ha) (C)	Per capita income (\$) (D)	Milk income share (%) (E)	Number of improved cows (F)	Number of local cows (G)	% of zero grazing (H)
Eastern	62	79	0.28	575	5.6	1.0	2.5	29.4
Central	300	80	0.37	519	19.5	2.2	0.0	58.7
Rift valley	221	204	0.47	500	22.7	3.2	1.4	15.6
Western	111	378	0.15	214	2.6	0.8	1.6	3.6
Nyanza	168	352	0.22	271	7.4	1.0	1.8	13.4

Table 5.2 Change in the number of households that owned improved cows

		2004		Total
		Not adopted	Adopted	1998
1998	Not adopted	310	343	653
	Adopted	49	160	209
Total	2004	359	503	862

All figures are the numbers of households

Table 5.3 Change in the number of livestock-related service providers

		Number of service providers of:					
		Veterinary service		Artificial insemination		Tsetse control	
		1998	2004	1998	2004	1998	2004
Province	Number of sub-locations (A)	(B)	(C)	(D)	(E)	(F)	(G)
Eastern	8	1.13	1.50	1.25	1.50	0.75	1.00
Central	35	1.17	1.83	0.91	1.57	0.86	1.54
Rift valley	25	1.12	1.64	0.96	1.20	0.52	0.92
Western	13	1.15	1.77	1.15	1.85	0.54	0.85
Nyanza	18	0.89	1.11	0.61	0.78	0.44	0.61

Table 5.4 Average milk price by traveling time to urban area and sales outlet^a

Traveling time to urban town	Retail price ^b (A) Kshs/l	Farm-gate price ^c (B) Kshs/l	Price spread ^d (C) Kshs/l	DID estimator PS2004–PS1998 (D)
1998				
0–15 min	29.7	24.7	5.0	–2.2
15–30 min	25.2	22.3	2.9	0.1
30–60 min	23.3	20.0	3.3	0.0
60 min –	26.3	18.0	8.3	–4.8
2004				
0–15 min	21.5	18.7	2.8	
15–30 min	18.3	15.3	3.0	
30–60 min	17.2	13.9	3.3	
60 min –	18.9	15.4	3.5	

^aMilk prices are adjusted for the 2004 October Kenya Shillings (Ksgs) per liter of milk. Deflators are from Statistical Bulletin, Central Bank of Kenya (June, 2002, 2004, and 2005)

^bThe retail price is the price paid by retail shops

^cFarm-gate price is the price paid by traders, processors, cooperatives, and KCC

^dThe price differentials between retail and farm-gate price ($P^R - P^F$)

allow us to separate the price differences in milk quality. However, since the raw milk price in Kenya does not reflect the quality of the milk, such as the fat content, calculating the milk price in this way should not create serious problems.⁶

⁶One of the reviewers argued that the disappearance of the formal distribution system resulted in lower “marketing costs” due to the deterioration of the quality of milk in the market since formal

In most areas, the retail price is higher than the farm-gate price (columns A and B), and both the retail and farm-gate prices tend to decrease as the traveling time to urban towns increases up to 60 min. The price spread between the retail and farm-gate prices is presented in column C. The change in the price spread at each traveling time category over time is presented in column D. This is the DID estimator explained in Eq. 5.1. We observe that the price spread, which is a proxy of the marketing costs, is lowest in the areas closest to urban towns and the areas farthest from urban towns. As shown in Table 5.4, the proportion of dairy farmers who sold milk to private traders in the areas closest to urban towns has increased threefold, from 14% to 42%, while the proportion of sales to cooperatives has decreased from 28% to 12%. Thus, such a dramatic increase of private traders' activities may have contributed to the reduction in the marketing costs as we discussed in Sect. 5.2.

Similarly, in the areas farthest away from urban towns, the proportion of dairy farmers who sold milk to dairy cooperatives declined from 31% to 5%; however, this reduction is most likely attributable, at least partly, to the bankruptcies of the dairy cooperatives. Thus, the reduction in the marketing costs could be due to the exit of poorly managed cooperatives from the market. Private traders, however, failed to replace dairy cooperatives in such areas because those who sold milk to private traders only increased from 0% to 9%. As a result, many dairy farmers sold milk to local customers instead, with this proportion increasing from 69% in 1998 to 86% in 2004 (Table 5.4, column E), in contrast to a decrease in this proportion (from 58% to 46%) for the areas closest to urban towns.

5.4 Results

We present in Table 5.5 the results based on the estimation of Eq. 5.2 with the milk price received by the farmer as the dependent variable. Columns A and B show the cross-section results for 1998 and 2004. In both years, the farm-gate price is significantly lower than the retail price. The difference between the two prices reflects mostly the marketing costs associated with traders collecting milk from dairy farmers for retail shops. We find that the traveling time variables are not significant in 1998 but become highly significant in 2004. As mentioned in Sect. 5.2, the dairy cooperatives and KCC offered a fixed milk price to dairy farmers, regardless of their location. Even after the liberalization, this policy was not completely removed. All members of a dairy cooperative, for instance, continued to receive a fixed price. Private traders, on the other hand, differentiated the milk price based on the transportation costs even within a community. Thus, the milk price became more sensitive to traveling time as the share of private traders increased in the marketing of milk.

processors test for quality and take a higher margin. To our knowledge, however, many informal traders also test milk by using lactometers. A study by SDP (2004) shows that there is no significant difference in the quality of milk sold by formal and informal traders.

Table 5.5 Determinants of milk price at the household level (sub-location fixed effects model)

	1998	2004	Pooled model
	(A)	(B)	(C)
Retail price dummy	0.940*	0.825**	2.163***
	(1.88)	(2.39)	(4.85)
Retail price dummy $\times$ years since 1st wave			-0.291***
$\times$ 2004 dummy			(3.43)
Years since 1st wave $\times$ 2004 dummy			-0.440**
			(2.39)
Travel time to urban town (min) $\times$ 0.01	-10.59	-20.91***	-5.444
	(-0.88)	(-2.85)	(0.77)
Travel time squared $\times$ 0.01	5.655	14.94**	4.854
	(0.65)	(2.55)	(0.89)
Travel time $\times$ years since 1st wave			-1.939***
$\times$ 2004 dummy $\times$ 0.01			(3.21)
Travel time squared $\times$ years since 1st wave			1.224***
$\times$ 2004 dummy $\times$ 0.01			(2.77)
Constant	27.17***	22.39***	23.99***
	(7.36)	(10.69)	(11.57)
Sub-location fixed effects	Included	Included	Included
Overall R-squared	0.11	0.14	0.41
Number of sub-locations	75	92	93
Number of observations	280	479	759

Observations include only those households that sold milk in the survey years

* Significant at 10%, ** significant at 5%, *** significant at 1%

In column C, we pool the two surveys and include the interaction terms. As explained in Eq. 5.2, the coefficient of the retail price dummy measures the marketing costs, and the coefficient of the interaction term of the retail price dummy and the years since the first wave indicates the change in the marketing costs. The positive coefficient of the retail price dummy variable captures the additional marketing costs associated with dairy farmers selling milk at retail shops than at the farm gate of the dairy farmers. The DID estimator of the price, δ , is negative and significant at the 1% level, indicating that the marketing cost has been reduced by about 0.3 Kshs per year between 1998 and 2004. This result supports Hypothesis 5.1.

The negative coefficient of 'years since the first wave' suggests that, compared with the first wave, the milk producer price at the farm gate declined in absolute terms. One possible explanation for this decline is the increased milk supply at the national level. According to FAOSTAT, the total milk production in Kenya increased from 2 billion tons in 1996 to 3 billion tons in 2004. This increase is evident among our samples: the proportion of dairy farmers who sold milk increased from 58% to 80% between the surveys. Although the decreased milk price may have reduced the producer profit, dairy farmers could have improved the production system to reduce the average cost of milk to remain profitable even under the decreased milk price.

5.5 Conclusions

This chapter examines the effects of restructuring the raw milk market in Kenya after market liberalization policies came into effect. According to the panel data of 862 households, the proportion of dairy households that sold milk to KCC and the dairy cooperatives drastically decreased from the late 1990s to 2004. The dairy cooperatives and KCC were replaced mainly by private traders and processors. Our results suggest that the marketing costs of milk have been reduced. Even though it is often said that rural markets do not work in African countries, private traders in the Kenyan milk market have been able to expand their businesses under severe competition, which has lowered the marketing costs as the results in this paper suggest.

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Chapter 6

Dynamic Changes in the Uptake of Dairy Technologies in the Kenya Highlands

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Abstract The purpose of this chapter is to investigate the dynamics in dairy production in the period following the liberalization using panel data on 874 agricultural households in the Kenya Highlands. Our estimation results indicate that the private milk marketing sector works effectively and thereby stimulates the adoption of improved dairy technologies. Similarly, we find that better market access facilitates the adoption of these technologies. In short, this chapter clearly demonstrates that improved marketing systems are a critical factor affecting the improvement of dairy production systems.

Keywords Technology adoption • Dairy production • Market liberalization • Agricultural policy • Kenya

6.1 Introduction

Understanding farmers' decisions to adopt agricultural innovations in developing countries is a major field of social science research. Adoption of new techniques or technologies is seen as the key to agricultural development and, hence, the analysis of the determinants of farmers' adoption is crucial to formulate policy recommendations for agricultural development. However, most analyses look at

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the adoption decision as a “snapshot” decision using cross-sectional data and do not take into account the dynamics of technology uptake.

Dairy farming is an important sector of the Kenyan economy, generating substantial income for the smallholders that produce more than half of the total milk production in Kenya (Omoro et al. 1999). Dairy is a major enterprise for 1.8 million smallholder households, keeping on average two cows on 2 ha of land (SDP 2006). Because milk production is on a daily basis, it provides for a regular source of consumption, income, and employment. Moreover, an estimated 365,000 wage jobs are created at the farm level (12% of the national agricultural workforce), in addition to family labor. Besides milk production for own consumption and sale, dairy provides manure and is a source of wealth and asset storage. The benefits of dairying do not, however, stop at the farm gate: there are substantial employment opportunities in milk marketing and services related to dairy production (provision of feeds, veterinary, breeding, and extension services). For example, almost 30,000 more jobs are generated by marketing and processing of milk, mainly in the small-scale informal sector.

The dairy sector is rapidly evolving with new players like private processors entering the market. The liberalization of the dairy industry in the early 1990s opened a new era for the dairy sector. With the progressive withdrawal of government livestock services and the end of the monopoly on urban milk sales held by a state-managed company Kenya Cooperative Creameries (KCC), the private sector was expected to fill the gap and to provide efficient services to the Kenyan smallholders. Uncertainty remains, however, as to whether the private sector is willing and able to provide these services, both on the production side (veterinary, breeding, and extension services) and on the marketing side. This is especially the case in areas where dairying is less market-oriented.

The purpose of this chapter is to investigate the dynamics in dairy production in the period following the liberalization using panel data (cross-sectional data over time) on 874 agricultural households in the Kenya Highlands. The objective is to identify opportunities for dairy growth and constraints to its development since dairy has been identified as a key pathway out of poverty for Kenyan households.

6.2 Dairy Markets and Technology Adoption in Kenya

6.2.1 Dairy Market Reform in Kenya

To guarantee a stable milk price to all dairy farmers following independence in the 1960s, the Kenyan government mandated that KCC accept all milk delivered to its plants and introduced a uniform pricing system (pan-seasonal and pan-territorial) in which KCC buys milk at the same price no matter where the dairy farmers are located and no matter when they sell their milk. The uniform pricing system was considered to have reduced the risk of adopting dairy cows by assuring that dairy

farmers could earn a stable income from milk production.¹ KCC, however, became bankrupt, and the indebted Kenyan government could not support it financially.

As a result, in 1992, the formal milk market was liberalized. Before that, KCC was the only company that was permitted to process milk, and selling raw milk in urban areas was prohibited.² The liberalization removed the ban on selling raw milk in urban areas, including Nairobi, and allowed private milk processing firms to buy milk from dairy farmers. Although the official intent of the 1992 dairy sector liberalization was only to allow sales of pasteurized milk products of private processors in urban areas, the interpretation by market actors was that all actors, including raw milk traders, could operate in urban areas (Owango et al. 1998). Therefore, the milk market liberalization in Kenya entailed the entry of private traders and private processing companies, and thus KCC lost its monopoly power in milk processing.

Although KCC continued to operate even after the liberalization, many of the dairy farmers sold milk to private processing companies and traders, instead of dairy cooperatives, in great part because KCC delayed payments to the dairy cooperatives and their members. Low levels of milk collection finally forced heavily indebted KCC to become bankrupt in 1998. Because the dairy cooperatives only sold milk to KCC, the shutdown of KCC in 1998 subsequently resulted in bankruptcies of many dairy cooperatives.

After the bankruptcies of the dairy cooperatives, private traders and processors replaced the cooperatives in the raw milk market. Such a replacement, however, did not take place without problems. While the dairy cooperatives purchased raw milk from members throughout the year, some traders tended to reject some of the milk during the rainy season due to the excess supply of milk. In addition, some traders disappeared without making payments to the dairy households, and some farmers and traders adulterated the milk to increase milk sales. Because of these problems with private traders, the closures of the dairy cooperatives created a need for a new marketing channel, which could prevent the recurrence of the problems (Staal et al. 1997; Holloway et al. 2000).

According to interviews conducted in January to March 2005 by the authors of this study,³ the frequency of problems related to milk marketing has declined as

¹Similar to other developing countries, there is seasonality in milk production in Kenya. This is due to the fact that feed are mainly grown under rainfed condition with limited feed conservation done. Since the milk production is seasonal, the price tends to fluctuate across seasons, if there is no price regulation.

²Ngigi (2005) notes that even before the liberalization, raw milk was directly sold to households in the neighborhood of the producing households in urban areas. However, raw milk traders were harassed by the police in urban areas, and the quantity of raw milk traded was considered to be much smaller before the liberalization than after the liberalization. This switch toward raw milk sales enables poorer urban consumers to increase their purchases of milk.

³As will be explained in the next section, the analyses in this study are conducted with the data collected in the rural household survey. The survey questionnaire covers questions related to household production and income but does not cover institutional changes in dairy marketing. To gain a better understating of the institutional changes of the milk marketing system during this transition period, we revisited the sample areas and interviewed traders, cooperative members, the KCC plant manager and workers, retailers, and dairy farmers.

trust-based and long-term relationships have developed between the traders and the dairy farmers and between the traders and retailers.⁴ Just after the collapse of the dairy cooperatives and KCC, the producers started transporting milk to nearby towns, and, some of the producers even started collecting milk from their neighbors and selling it in towns (Karanja 2003). There were few long-distance traders transporting the raw milk to large cities in this period, though. This is because trading raw milk in large quantities over a long distance requires capital to purchase pick-up trucks. More importantly, because the raw milk was sold without processing and packaging, it was difficult for the traders to sell raw milk in large cities when there were no institutions to assure the quality of the raw milk. As traders established milk marketing retail chains of kiosks, generally called “milk bars,” and brand names to gain a good reputation regarding quality and safety, the number of long-distance raw milk traders has increased to fill the gap between the milk demand and supply (Argwings-Kodhek and Karin 1999). We believe that the institutional changes in the milk marketing, described above, have reduced the marketing costs of raw milk, especially transaction costs, such as the information costs of searching for markets and making contracts, negotiating costs, and monitoring and enforcement costs. Thus, in the following sections, we analyze the effects of these policy and institutional changes on marketing costs and on household behavior regarding milk production and marketing.

In the process of the liberalization of the dairy sector, dairy farmers lost access to subsidized veterinary and extension service providers. Before the liberalization, public extension services provided these services. After the liberalization, however, the public extension services have been unable to provide subsidized services to dairy farmers because of budget shortages. Although it was expected that the private sector would fill the gap in the provision of dairy services, the gap remains largely unfilled. Thus, there remain questions on the extent and source of services received by dairy farmers and who are potential services providers to fill the gap.

The literature is rich in examples of static analyses linking a certain measure of adoption- or uptake- (e.g., farmers’ decision to use an improved crop variety, or the extent of the land allocated to the new variety) to the adoption determinants. Determinants usually include farmer’s characteristics, farm characteristics, external factors and in some cases, farmers’ perceptions of the new technology. Usually, cross-sectional household survey data are used. However, it is well known that farmers may discontinue adoption, and understanding the dynamics of uptake is needed to formulate relevant policy recommendations. This is particularly important in cases of change in external factors, for example, sector liberalization or major change in marketing channel as in the case of dairying in Kenya.

⁴ As Hayami and Kawagoe (1993) discuss, transactions based on local connections and family ties have the feature of restraining business counterparts from breaking rules. In our study areas, many small vendors collect milk from their neighboring dairy farms. Because of the local connection, it should not be so difficult for vendors to supervise the farms so that the farms do not dilute their milk by adding water. Cheating in transactions between vendors and traders has been kept under control to some extent by conducting milk tests randomly.

6.3 Descriptive Statistics and Estimation Methods

6.3.1 Data

The first round of data was collected between 1996 and 2000 in central and western Kenya, as part of an effort to characterize smallholder dairy systems by a collaborative team from the Ministry of Livestock Development & Fisheries, the Kenya Agricultural Research Institute (KARI), and the International Livestock Research Institute (ILRI). Similar sampling methods were applied in each case, and each survey used a variant of the same data collection instrument, conducted in a single interview of each household. The survey collected a wide variety of data on household resources, land use and livestock management practices, livestock inventory, recall of feed and other input use, and the use of livestock and extension services. Areas were delineated according to agroecological production potential and market access. A total of 3,330 randomly selected households were interviewed. Each household was geo-referenced using GPS unit. It is therefore possible to link each household to geographical information systems (GIS) data layers, e.g., agro-climatic, road network, and other infrastructure. More information is provided in the survey reports (Staal et al. 1998, 2001; Waithaka et al. 2002).

The second round of data was collected in 2004 on 895 households previously surveyed. The questionnaire included most of the information collected during the first round. More information on the crop side was collected (see Yamano et al. 2005). Note that for simplification, the year “2000” is used to describe the data collected between 1996 and 2000, and the year “2004” is used to describe the data collected in 2004. The two datasets were combined to allow analysis of the change in choice of marketing outlets and technologies.

6.3.2 Descriptive Statistics

To examine whether there is any difference in milk marketing across areas, Table 6.1 presents the percentages of households that produced and sold milk in 2000 and 2004 by the traveling time to urban towns. There are two important findings in this table. First, the proportion of households that produced milk slightly increased from 60% to 64%, and this change does not have a clear correlation with the traveling time to urban towns. Second, there is a large increase in the proportion of households selling milk, from 58% to 80%, among milk producers between 1998 and 2004, and there is a tendency that the proportion of households selling milk is higher in areas closer to urban towns. This is probably because it is less costly to transfer raw milk from dairy farmers to urban consumers if the dairy farmers are located close to urban towns, where the demand for raw milk is especially high.

The next table, Table 6.2, shows the percentages of milk producers who sold milk to the three different milk buyer types, i.e., local customers, cooperatives/

Table 6.1 Sample households in Kenya in 2000 and 2004

	Number of Households	Percentage of Households who Produced Milk	Percentage of Households who Sold Milk	Percentage of Producers who Milk
Traveling Time to Urban Town	(A) Number	(B) % of A	(C) % of A	(D) % of B
2000				
0–15 min	127	55	38	69
15–30 min	280	61	41	67
30–60 min	361	62	32	51
60 min –	94	62	28	45
Total	862	60	35	58
2004				
0–15 min	127	54	43	80
15–30 min	280	65	56	86
30–60 min	361	69	54	79
60 min –	94	59	37	64
Total	862	64	51	80

Table 6.2 Distribution milk outlets by the distance to Nairobi

	% of sellers sold milk to:		
Traveling time to urban town ^a	Local customers ^b	Cooperatives and KCC	Traders and private processors
	(A)	(B)	(C)
2000			
0–15 min	58	28	14
15–30 min	41	38	21
30–60 min	55	20	25
60 min –	69	31	0
Total	51	29	20
2004			
0–15 min	46	12	42
15–30 min	36	20	44
30–60 min	49	6	45
60 min –	86	5	9
Total	47	12	41

^a“Traveling time to urban town” is the average traveling time to the closest urban city from each household. This variable is measured by GPS information, which identifies three types of road: tarmac, other all-weather road, and dry-weather road. To calculate traveling time, tarmac road can be driven at 80 km/h, other all-weather road can be driven at 50 km/h, and dry-weather road can be driven at 30 km/h

^b“Local Customers” includes restaurants, hotels, kiosks, and individual customers

KCC, and private traders/processors. We find that, in 2000, half of the milk sellers sold milk to local customers and the share of KCC/cooperatives was about 30% regardless of the distance to urban towns. In 2004, the share of KCC/cooperatives declined to 12%. It is interesting to observe that the cooperatives could maintain

Table 6.3 Change in uptake of dairy technologies over time

	Grade cattle	Planted fodder	Feeding concentrate
	(A)	(B)	(C)
Non-adopter	282 (33%)	276 (32%)	437 (55%)
New adopter (Adopter only in 2004)	117 (13%)	207 (24%)	118 (15%)
Dis-adopter (Adopter only in 2000)	78 (9%)	64 (8%)	122 (16%)
Continuous adopter (Adopter in both years)	394 (45%)	312 (36%)	111 (14%)
Total	(100%)	(100%)	(100%)

relatively high shares in areas closer to towns but lost their shares significantly in areas farther away from towns. After the bankruptcy of KCC, which was the only milk buyer for most cooperatives, in 1998, the cooperatives had to establish new milk marketing channels. Cooperatives in areas close to urban towns could easily establish new marketing channels to urban consumers, while cooperatives in remote areas had greater difficulty to establish long-distance marketing channels to urban consumers. This is probably why we find relatively greater market shares of cooperatives located in near urban areas. In contrast, private traders and processors gained shares in all areas, except the most remote areas. In the most remote areas, which are at least 60 min' driving distance or farther from towns, the share of local customers increased from 69% to 86% from 1998 to 2004. Thus, in these remote areas, private traders and processors failed to replace dairy cooperatives as milk buyers.

Although private traders have replaced cooperatives in milk marketing, in high market potential areas, it does not seem that the private sector has provided veterinary and extension services that were provided by the public sector. Lack of such services may have slowed down or even reversed technology adoption in the dairy sector. Thus, in Table 6.3, we examine dynamics in the uptake of the three technologies, i.e., grade cattle, feeding concentrate, and planting fodder. In this table, dairy farmers are grouped into four groups: "Non-Adopter," "New Adopter," "Dis-adopter," and "Continuous Adopter." According to the results in Table 6.3, approximately 33% of the households did not keep grade cattle in any of the 2 years, while 45% kept them continuously in the two periods. Thirteen percent kept grade cattle only in 2004, meaning that they are "new adopters," while 9% of them are dis-adopters who kept grade cattle only in 2000. The adoption patterns are similar for planting fodders, though there was a higher proportion of new adopters. It seems that dairy farmers adopt fodders mainly when they adopt grade cattle; however, there is an indication that some farmers may be planting fodder with the intention of selling it. Regarding feeding concentrate, we find that about 55% of them are non-adopters. We also find that, while there are new adopters, there are also some dis-adopters in roughly equal percentages (15–16%). These variations help us identify factors that are associated with adoption and dis-adoption of these technologies. In the next section, we discuss our estimation strategies to estimate dynamic adoption model.

6.3.3 Estimation Method

Since the household data are available at two points in time, panel data techniques can be used to identify the factors influencing dairy technology uptake over time and over space. Various estimators (between, within, and random) are available and by exploiting the time dimension and controlling for unobserved household heterogeneity, the results would be more efficient than the majority of previous analyses on cross-sectional data. However, the analyses conducted in this paper use limited dependent variables and panel data techniques on such variables differ from linear regression techniques. In fact, there is no fixed-effects estimator for probit since heterogeneity cannot be extracted from the likelihood. A random effect estimator exists for probit using a specific estimation technique (Gauss-Hermite quadrature) but the applicability of this numeric method needs to be checked and is more applicable to small panel data, which is not the case here. On the other hand, a fixed effects estimator exists for logit model since it is possible to remove the heterogeneity by taking deviations from the means but when using logit fixed-effects model, only individuals experiencing a change can be taken into account.

The selected approach is therefore to analyse how systems have changed and identify the factors driving these changes. To do so, the dependent variable represents the change in farmers' uptake of a particular technology (e.g., less intensified system, no change, more intensified system). Two types of explanatory variables are included: variables evaluated at the first point of time (2000) and at the second point of time (2004) for variables for which values at the two points of time are available. GIS-derived variables are only available for 2000. When no major change for a particular variable was recorded within household, only the 2000 value was included so as to avoid introducing multicollinearity.

Each year t , the household is assumed to maximize total household income, which is equal to the sum of the profits derived from the farm activities (crops and dairy activities) and the earnings from family off-farm labor. The choice variables at year t are the land area devoted to each crop activity and to the livestock activity (including area under planted fodder F_t), labor for each activity, purchased inputs (including quantity of concentrates to be fed to cattle C_t , and the number of grade cattle (G_t). A farmer decides to adopt one of the three technologies under study (planted fodder, feeding concentrates, and keeping grade cattle) at time t if the optimal level of technology is positive, i.e., $F_t^* > 0$, $C_t^* > 0$ and $G_t^* > 0$. At each point in time, the decision to adopt the specific technology can then be written as

$$Y_{i,t} = 1 \quad \text{if } Z_{i,t}^* > 0 \Rightarrow X_{i,t} \cdot \beta + e_{i,t} > 0 \quad \text{farmer } i \text{ decides to adopt} \quad (6.1)$$

$$Y_{i,t} = 1 \quad \text{if } Z_{i,t}^* < 0 \Rightarrow X_{i,t} \cdot \beta + e_{i,t} < 0 \quad \text{farmer } i \text{ decides not to adopt} \quad (6.2)$$

with $Z = F, C$, or G

where $X_{i,t}$ is a vector of explanatory variables, β a vector of coefficients to be estimated, and $e_{i,t}$ is an independently and identically distributed farm specific ex ante shocks. Following Feder et al. (1985), the vector of explanatory variables includes farm and farmer's characteristics as well as external factors. Literature and fieldwork

experience dictate the choice of the explanatory variables to be included in the analysis.

Among the explanatory variables are measures of the availability of various milk marketing outlets (local markets; cooperatives and KCC; and traders and private processors) expressed as the proportion of farmers in the area selling to those outlets. Cooperatives, KCC, as well as processors and, to some extent, traders offer more reliable outlets than local markets and some provide services like feeds and breeding services on credit. Change in the extent of farmers selling to those outlets between the two periods (2000 and 2004) aims at capturing market dynamics and their effects on dairy technology uptake.

Intensification in dairy farming is a multidimensional process. The overall objective is to increase farm productivity (either through increase in milk production per cow or per unit of land, or both). To intensify, farmers therefore must invest in high-producing animals (improved cattle), i.e., cattle whose genetic potential allows higher milk production than local breed cattle. Another way to increase cow productivity is to improve feeding, in particular, through feeding of fodder (like Napier grass in the study area) and concentrates (like dairy meal or agro-industrial by-products). Three indicators of technology uptake are therefore analyzed, namely whether the farmer keeps improved cattle, whether concentrates are fed and whether planted fodder are fed to cattle. Grade cattle are defined as cattle with at least 50% of exotic dairy genes. Note that in the “2000 data,” cattle genotype is defined as local, cross bred, or high grade cattle but in the “2004 data,” cattle are identified as either local or improved. To be able to compare the datasets, the two last genotypes of the “2000 data” are lumped together to be comparable to the “improved” category of the “2004 data.”

6.4 Estimation Results

A multinomial logit is estimated with the dependent variable taking values of 1 for farmers who did not keep improved cattle in any of the 2 years, 2 for those who kept improved cattle only in 2004, 3 for those who kept them only in 2000, and 4 for those who kept them in the two periods. The comparison group is the group of farmers who kept improved cattle both in 2000 and 2004. A similar analysis is run for the two other indicators of dairy intensification. Results are presented in Table 6.4. Goodness of fit indicators are not straightforward for a multinomial logit; predicted probabilities were computed for the four possible outcomes and the maximum predicted probability was assumed to be the predicted outcome. The comparison of the observed and the predicted outcomes shows that various models predict correctly between 56% and 61% of the observations.

For each indicator, there are three sets of results: the first column of results gives the marginal effect of a one-unit change in the explanatory variables on the probability of being a non-adopter, compared to the probability of being an adopter in both years (which we call a “continuous adopter”). The second set of results show the marginal effect of being a “new adopter” (an adopter only in the 2004 dataset),

Table 6.4 Decision to keep grade cattle, to feed concentrates, and to grow fodder (multinomial logit, marginal effects)

Variable	Decision to keep improved cattle			Decision to feed concentrates			Decision to grow fodder		
	Non-adopters	New adopters	Dis-adopters	Non-adopters	New adopters	Dis-adopters	Non-adopters	New adopters	Dis-adopters
Female head dummy	-0.021	0.071*	-0.055**	-0.009	-0.027	-0.023	-0.008	0.018	0.003
Age of the household head	0.003*	-0.003**	0.002**	0.002	-0.001	0.000	0.001	0.001	0.001
Education of the household head	-0.011**	-0.001	0.001	-0.016***	-0.001	0.006	-0.006	0.004	0.001
Number of adults	-0.002	0.001	-0.007	-0.002	0.001	0.007	-0.011	0.004	-0.003
Ratio of female adults over total adults	0.076	-0.093	0.028	0.195*	-0.013	-0.047	0.032	0.110	-0.012
Dependency ratio	0.153	0.019	-0.032	0.007	0.061	0.026	0.124	0.012	0.026
Land size	-0.024***	-0.013**	-0.003	-0.017***	0.001	0.005	-0.008	-0.013**	0.008***
Population density	0.000*	0.000	0.000*	0.000	0.000	0.000	-0.001***	0.000*	0.000***
PPE	-0.805***	0.024	-0.042	-0.602***	0.354***	0.167	-0.867***	-0.034	-0.004
<i>Distance to the two nearest large urban center</i>									
Tarmac roads	-0.002	-0.001	0.001	0.001	0.001	-0.001	0.002	-0.001	0.000
Other all-weather roads	0.007**	0.001	-0.002	0.005*	0.003*	-0.004*	0.007***	-0.004	0.000
Dry-weather roads	0.003	-0.008*	-0.003	0.003	-0.008*	0.002	-0.002	-0.003	0.000
Travel time to Nairobi	0.083***	0.013	0.008	0.134***	-0.076***	-0.037**	0.128***	-0.027	0.019
Proportion farmers selling to local customers	-0.002	0.072	-0.070	-0.371***	-0.053	0.260**	-0.131*	-0.026	0.032
Proportion farmers selling to coop and KCC	-0.203	-0.131	0.087	-0.717***	-0.052	0.453***	-0.213	-0.112	0.107
Proportion farmers selling to local traders and processors	-0.727***	0.001	-0.015	-0.626***	-0.058	0.364***	-0.207*	-0.176*	0.144**
Change in proportion of farmers selling to local customers	0.104	0.036	-0.069	-0.258*	0.024	0.172	-0.008	0.020	-0.004
Change in proportion of farmers selling to coop and KCC	0.017	-0.089	0.099	-0.599***	0.090	0.372**	0.071	-0.026	0.004
Change in proportion of farmers selling to local traders and processors	-0.310***	0.070	-0.069	-0.378***	0.063	0.214	0.110	-0.009	0.013
Number of households	798			720			788		

Change in proportion expressed between 2000 and 2004. Base category is continuous adopters

* Significant at 10%, ** significant at 5%, *** significant at 1%

compared to a “continuous adopter,” while the third set of results show the marginal effect of being a “dis-adopter” (an adopter only in the 2000 dataset), compared to a “continuous adopter.” Maybe because the dis-adopters represent a small proportion of the farmers, some of the results for this category of farmers are more difficult to interpret and should be interpreted with caution.

In terms of survey-derived variables, the education level of the household head has a significant effect on the decision to keep grade cattle and concentrate feeding. In fact, more educated households are more likely to be continuous adopters of grade cattle cum concentrate feeding technologies, results that confirm the positive relationship between education and uptake of improved dairy farming technologies found in cross-sectional analyses. As expected, older households are less likely to be new adopters and more likely to dis-adopt grade cattle technology, while female-headed households are more likely to be new adopters and less likely to stop dairy farming.

The land size results show that compared to those who keep grade cattle in both surveys, farmers with no grade cattle in any of the two rounds and new adopters have less land, suggesting that large land size is needed for continuous uptake but farmers with small land size are able to start keeping grade cattle. As for concentrate feeding, larger landholdings are positively associated with continuous adoption, which could be interpreted as a wealth effect. Farmers who start growing fodder are those with less land, suggesting that under decreasing land availability, farmers find it appropriate to intensify dairy production by allocating some land to a dairy specialized crop.

Now turning to the GIS-derived variables, the indicator of climatic conditions (PPE) has a significant effect on each technology decision. Farmers in good climatic areas have a higher probability to be continuous adopters of grade cattle, concentrate feeding, and fodder technologies. The effect of human population density is significant in the fodder regression, which indicates that farmers in high density areas are more likely to be continuous adopters or new adopters, a result consistent with Boserup’s hypothesis. On the other hand and unexpectedly, farmers not keeping improved cattle or those stopping to keep them and those stopping growing fodder are those in high population densities areas.

The market access variables show interesting results: consistently, households closer to Nairobi (in terms of travel time) are more likely to be continuous adopters of the three technologies. Farmers close to Nairobi are also more likely to start feeding concentrates, illustrating a strong market push. However, higher travel time to Nairobi is also associated with lower likelihood of stopping to feed concentrates. Access to urban centers is also a significant factor in the three regressions: increased distance (low market access) is positively correlated with the probability of not keeping improved cattle, growing fodder, and feeding concentrates in any of the two periods. Distance on dry weather road also matters: farmers with low market access (high distance) are less likely to start keeping improved cattle and feeding concentrates. These results clearly support Hypothesis 2 of the book that farmers respond to improved market condition by adopting new profitable technologies. For concentrate feeding, the results for the distance to urban centers variable on other all-weather roads for new adopters and dis-adopters are unexpected.

We now turn to the interpretation of the market outlets variables. Overall, areas with high availability of traders and processors (as captured by the proportion of farmers selling to those outlets) are characterized by high rate of continuous uptake of the three technologies (compared to non adoption). Also, areas that experienced increase in traders and processors' activities (over time) are those with higher rate of continuous uptake of improved cattle and concentrate feeding. Thus, these results suggest that expanded activities of private traders after the milk market liberalization have encouraged dairy farmers to adopt improved dairy cattle technologies, probably because dairy farmers consider private traders as reliable milk outlets. Thus, it appears that milk markets are functioning well under the liberalized marketing policy, which is consistent with Hypothesis 1.

Regarding concentrate feeding, irrespective of the type of market outlets, higher availability translates into lower non adoption (or more continuous uptake). This also applies to change over time: irrespective of the market outlets, higher availability over time translates into higher continuous uptake (compared to non adoption). There are some unexpected results on dis-adoption of concentrates feeding, maybe due to few observations: irrespective of market outlets, higher availability translates into more disadoption. As for the decision to grow fodder, the higher the proportion of farmers selling to local markets or to local traders, the more likely farmers to be continuous adopters (compared to non-adopters). On the other hand, the higher the proportion of farmers selling to traders, the less likely to be new adopters and the more likely to dis-adopt.

6.5 Conclusions

A number of analyses have previously been conducted on the uptake of agricultural innovations in developing countries, in general, and uptake of dairy technologies, in particular. Most studies, however, use cross-sectional data and therefore analyze a dynamic process in a static way. In this chapter, we used panel data collected on 874 farmers over two periods of time to analyze the dynamics of uptake of dairy technologies. Different indicators of dairy technologies were used and the results confirm those of cross-sectional analyses on the effects of education and landholdings, among other things.

In Kenya, the milk market has been evolving rapidly with important changes in the type of marketing outlets available to smallholders. Our estimation results strongly indicated that the private milk marketing sector works effectively and thereby stimulates the adoption of improved dairy technologies. Similarly, we found that better market access facilitates the adoption of these technologies. In short, this chapter clearly demonstrated that improved marketing systems are a critical factor affecting the improvement of dairy production systems. Thus, further public and private sector efforts should be made to improve marketing systems in Kenya with a view to enhancing the efficiency of dairy production sector as a whole.

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Chapter 7

Mobile Phone Coverage and Market Participation: The Case of Banana Marketing in Uganda

Megumi Muto and Takashi Yamano

Abstract Increased information flow due to mobile phone network expansions is expected to reduce marketing costs of agricultural commodities. We investigate this using panel data of 856 Ugandan households in 94 communities, where the number of communities covered by mobile phone networks increased from 41 to 87 between surveys in 2003 and 2005, respectively. After the expansion of coverage, we find increased sales of banana in remote communities but not of maize. The mobile phone coverage expansion seems to induce the market participation of farmers in remote areas who produce perishable crops.

Keywords Information technology • Marketing • Panel data • Uganda • Africa

7.1 Introduction

A dramatic change in the use of information technology is taking place across African markets (The New York Times 2005; Donner 2004). Indeed, mobile phone networks have been expanding rapidly in many African countries, where the average number of mobile phone units per 100 inhabitants reached 9.1 in 2004, with an annual growth rate from 1999 to 2004 of 59.7% (ITU 2007). Improved information technology is expected to reduce marketing costs, which include search and transportation costs. Bayes (2001), for example, reports that agricultural output prices are higher when villages are equipped with pay phones in Bangladesh.

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In Ghana, Overa (2006) finds from a survey that Ghanaian traders reduce food spoilage by efficient marketing using mobile phones.

More rigorously, Jensen (2007) identifies the impact of the introduction of mobile phones on marketing in India. He shows that fishermen increase arbitrage among local fish markets after the introduction of mobile phones, leading to a decline in the variation in fish prices and a reduction in spoilage. Also in India, Goyal (2008) uses a market level dataset to identify an increase in the market price of soybeans after Internet kiosks were introduced. Aker (2008) carefully compiles secondary market price data on grains across 42 domestic and cross-border markets in Niger and finds that the use of mobile phones reduces grain price dispersion across markets by a minimum of 6.4% and reduces intra-annual price variation by 12%. Because she uses market and trader data, however, she does not examine the impacts of the mobile phones on farmers' behaviors. Indeed, no previous study has estimated the impacts of the mobile phone network expansion on farmers' market participation.

The purpose of this chapter is to estimate the impact of mobile phone network expansion on farmers' market participation in Uganda. In Uganda, the coverage of the mobile phone network expanded from 46.0% of the population in 2003 to 70.0% in 2005 (ITU 2007). In the present study, we use panel data of 856 households in 94 communities across the country, excluding the northern regions. During the 2-year period between the first survey in 2003 and the second survey in 2005, we find that the mobile phone network expanded from 41 to 87 communities. The mobile phone network was not yet available in the remaining seven communities even in 2005. Although the increased flow of information can potentially benefit the marketing of all kinds of crops, we expect that it has a larger impact on perishable products than on cereals because the prices of perishable products depend heavily on freshness at the time of exchange. In Uganda, banana is an important staple crop and is highly perishable.¹ Thus, we focus on the impact of the mobile phone coverage on banana marketing in this chapter.

In the next section, we present the conceptual framework. Section 7.3 describes the data collection and examines relevant descriptive statistics, while Sect. 7.4 explains the estimation method. The estimation results are reported in Sect. 7.5, followed by the discussion and conclusion in Sect. 7.6.

7.2 Conceptual Framework

In this section, we present a simple model on the farm-gate price of banana and apply the model to banana marketing in Uganda. Suppose that the farm-gate price of banana of farmer i at time t is defined as $p_{it}^F = p_t^M - \gamma \tau_i$, where p_{ij}^F is the banana

¹Plantain (cooking banana) is the dominant banana variety in Uganda. In our sample, more than 90% of the bananas are plantain. The rest are brewing and dessert bananas. Although we know the variety of banana produced by our sample farmers, we do not know the quality, such as weight and taste.

farm-gate price, p_t^M is the price of banana at the nearest market from the household i at time t , γ is the marketing cost per unit of distance, and τ_i is the distance between the market and farmer i . We assume that γ represents the sensitivity of the output price of banana with regard to the distance to the market.

To investigate the impacts of the mobile phone network on banana marketing, we introduce the information technology, I_t , and assume that the marketing cost of banana per the distance unit, γ , is a function of the information technology, where the marketing cost decreases as the information technology improves: $\frac{\partial \gamma_j(I_t)}{\partial I_t} < 0$. Thus, the mobile phone network coverage decreases the marketing cost of banana by improving the information technology, leading to a lower level of $\gamma_j(I_t)$. We think that the marginal change in $\gamma_j(I_t)$ due to a one unit increase in the information technology, I_t , is expected to be large for perishable crops, such as banana. The potential gain for farmer i when the information technology improves, while keeping the market price and distance constant, can be derived as

$$\begin{aligned} \Delta p_{it}^F &= p_{i2}^F - p_{i1}^F, \\ &= p^M - \gamma(I_2)\tau_i - p^M + \gamma(I_1)\tau_i, \\ &= -\{\gamma(I_2) - \gamma(I_1)\}\tau_i, \end{aligned} \tag{7.1}$$

where $I_2 > I_1$ and $\{\gamma(I_2) - \gamma(I_1)\} < 0$. Thus, the banana farmers should gain by the introduction of the mobile phone network, and the gain should be larger for farmers who are located farther away from the market. Note again that the impact of the introduction of the mobile phone network is larger for more perishable crops than for less perishable crops because of higher marketing costs induced partly by the need to quickly negotiate sales.²

Before the introduction of mobile phones, town-based traders used to visit banana producing areas without any prior announcement due to the lack of any communication methods. While there, they would spend several days to collect banana bunches by sending out village-based buyers on bicycles until they had collected enough to fill their trucks. For banana farmers, this could be the only available option to sell their banana to outsiders. Because it is costly to transport banana bunches, banana farmers often wait for traders to come by and, as a result, they do not have much bargaining power over the price the traders offer, particularly if they do not have information on the prevailing price in the market. Moreover, in Uganda, it was uncommon to find farmer associations where farmers could potentially share market information (Smale and Tushemereirwe 2007).

²In Muto and Yamano (2009), we compare the same model for banana and maize, which is less perishable than banana. We do not find any significant impacts of the mobile phone network on maize price and marketing.

The introduction of mobile phones has changed this situation in some areas. When areas are covered by the mobile phone network, individual banana farmers or their representatives could contact banana traders in advance and negotiate the price and set up a time and place to sell banana. Banana farmers can select a trader who offers the highest buying price by making phone calls to some potential buyers. Because one representative can negotiate with traders on behalf of fellow banana producers, who are relatives and friends in the same community, individual banana producers do not need to own mobile phone units. Further, such arrangements of negotiation with the traders by a representative of the community facilitate business transactions without breaking community rules as discussed by Hayami and Kawagoe (1993). For traders, prearrangements can reduce their transaction costs significantly because they can fill their trucks in a few hours by making prearrangements and transport fresh bananas to urban markets. Fresh bananas collected in such an efficient transaction can fetch higher prices at urban markets and have less spoilage. Thus, the benefits from the reduced transaction costs could be shared by both banana producers and traders.

7.3 Data

We use data from household and community surveys in Uganda collected as part of the Research on Poverty, Environment, and Agricultural Technology (RePEAT) project. The sample for the RePEAT project largely builds upon and complements a completed research project on policies for improved land management in Uganda, conducted by IFPRI and Makerere University between 1999 and 2001 (Pender et al. 2004). The latter involved a survey of 107 Local Council 1s (LC1s)³ selected from two-thirds of the regions in Uganda, including more densely populated and more secure areas in the southwest, central, east, and parts of northern Uganda and representing seven of the nine major farming systems of the country. Because of insecurity problems in the north and northeastern part of the country, we excluded LC1s in this region from our samples. The RePEAT project was conducted in 29 out of 32 districts and in 94 out of 107 LC1s studied by IFPRI. From each LC1, 10 households were selected to make a total of 940 sample households. The RePEAT surveys were jointly conducted by Makerere University, the Foundation for Advanced Studies on International Development (FASID), and the National Graduate Institute for Policy Studies (GRIPS) in 2003 and 2005. In 2005, a follow-up survey of the 940 households was conducted, and 856 households were interviewed successfully. In both surveys, community surveys were also conducted along with the household surveys.

³Local Council 1 (LC1) is the lowest administrative unit in Uganda.

The dataset includes information on spatial location and infrastructure such as distance to district centers/markets, information on mobile phone network availability, as well as mobile phone possession by the sample households.⁴ We stratify our samples by the network in Table 7.1. The proportion of the sampled households covered by the network increased from 42% to 92% between the surveys. As for household mobile phone ownership, only 4.3% of the households possessed at least one unit in 2003, while in 2005 the percentage increased to 11.5%.⁵ As we show in Fig. 7.1, the mobile phone network was first established in the central and eastern parts of Uganda where the population density is high and the economy is advanced. Along the highway between western Kenya and Kampala, several industrial clusters, such as Jinja, are located.

In Table 7.2, we stratify our sample of banana farmers into three groups according to the timing of the mobile phone coverage and present the proportion of households that sold banana and the ratio of sales to production. The first group is the households that attained the coverage between the 2003 and 2005 surveys (N/Y group), and the second group is the households that were covered by the network at the time of the 2003 survey (Y/Y group). The third group is the households that have never been covered by the network (N/N group). The number of sample households in this last group is only 7.9% of the total sample. Then, we further stratify our samples by the distance to the district centers, where markets are usually located, because we think that the size of the impact of the mobile phone network on banana sales depends on the distance to markets.

Table 7.1 Mobile phone network coverage and ownership

Region	Number (%) of households	Number (%) of sample households by mobile phone network coverage			Proportion (%) of households who own mobile phone units	
		2003 and 2005	Only in 2005	Never covered	2003	2005
Eastern	383 (44.7)	133 (34.7)	221 (57.7)	29 (7.5)	2.6	8.6
Central	250 (29.2)	123 (49.2)	127 (50.8)	0 (0)	8.0	17.6
Western	223 (26.0)	107 (47.9)	77 (34.5)	39 (17.4)	3.1	9.8
Total	856 (100)	363 (42.4)	425 (49.6)	68 (7.9)	4.3	11.5

⁴In the 2005 community surveys, we asked the timing of when the community was covered by the mobile phone network.

⁵Note that there are some households that own mobile phones in communities that are not covered by the network. We think that they own the phones to use when they travel to areas, such as large cities, that are covered.

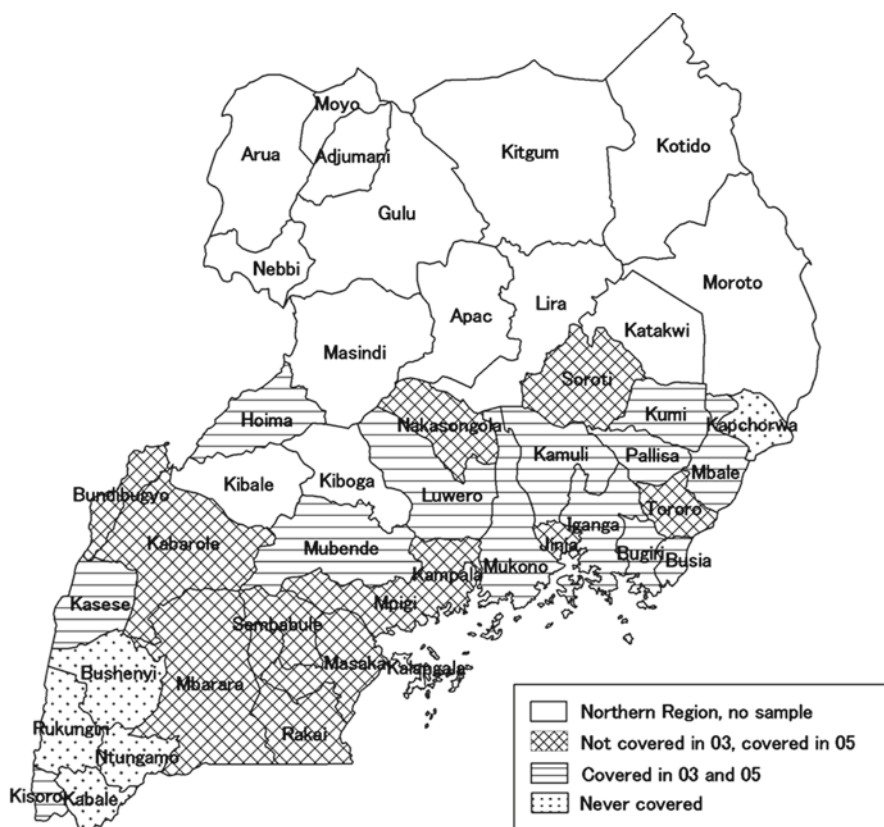


Fig. 7.1 Mobile phone network expansion in Uganda

Regarding the marketing of banana, we find a large increase in the ratio of households selling banana in locations more than 20 miles away from the district centers.⁶ The proportion of households that sold banana increased from 43% in 2003 to 68% in 2005 in locations where the mobile phone network became available after the 2003 survey. We also find that the proportion of banana sales to production increased by 11.2% points among the same group. In contrast, the proportion of households that sold banana and the proportion of banana sales to production did not increase significantly in locations where the mobile phone network was already available in 2003. Thus, we conjecture that the mobile phone network increased banana sales in locations farther away from district centers. As for locations never covered by the network, the ratio of sellers to producers increased in areas less than 20 miles from the district centers. The ratio of sales to production did not increase

⁶In the descriptive statistics, we compare locations more than 20 miles away and less than 20 miles away since our nonparametric analysis suggests that in locations less than 20 miles away, prices decline with distance but not beyond 20 miles, possibly due to an increase in supply from more distant production areas.

Table 7.2 Ratio of banana sellers and sales by mobile phone coverage

	Mobile coverage	Ratio of sellers to producers (%)			Ratio of sales to production (%)		
		2003	2005	Dif. (<i>t</i> -value)	2003	2005	Dif. (<i>t</i> -value)
All locations	N/Y	48.3	53.4	5.1* (1.84)	20.0	24.6	4.6*** (2.70)
	Y/Y	54.0	50.7	-3.3 (0.11)	19.6	22.8	3.2** (2.44)
	N/N	74.4	83.7	9.3* (1.70)	24.0	27.2	3.2 (1.38)
More than 20 miles	N/Y	42.9	68.0	25.1** (2.50)	19.0	30.2	11.2*** (2.81)
	Y/Y	67.5	72.2	4.7 (0.00)	25.2	26.8	1.6 (0.19)
	N/N	25.0	25.0	0.00 (1.00)	16.6	5.5	-11.1 (1.00)
Less than 20 miles	N/Y	47.6	46.1	-1.5 (0.13)	20.8	22.0	1.2 (1.01)
	Y/Y	50.9	46.5	-4.4 (0.12)	18.5	21.2	2.7** (2.26)
	N/N	76.6	90.0	13.4* (1.68)	23.8	26.4	2.6 (0.58)

N/Y indicates the group of households that were not covered by the mobile phone network in 2003 but covered in 2005. Y/Y indicates the group of households that were covered by the mobile phone network both in 2003 and 2005

Numbers in parentheses are absolute *t*-values

* Significant at 10%, ** significant at 5%, *** significant at 1%

in this category. The increase in the ratio of sellers may be a result of the diffusion of market price information through a mechanism other than mobile phones in areas close to the district center.

7.4 Estimation Models and Variables

In general, the mobile phone network in Uganda covered populated areas first and then expanded to remote areas. Thus, we expect that the mobile phone network coverage is associated with community-level characteristics. To confirm our expectation, we first estimate the determinants of the mobile phone network coverage. Further, the possession of mobile phones at the household level is a choice variable, and we need to treat it as an endogenous variable in the models of banana market participation and income. Thus, we estimate the determinants of mobile phone possession at the household level and find the proper instrumental variables to be used in the following models. Then, we estimate the determinants of banana market participation, the proportion of sales to the total production of banana, and total banana production income.

As explanatory variables, we include a 2005 survey year dummy, *yr05*, a dummy for the community-level mobile phone network coverage, *LC1mob*, and the distance from the community to the nearest district center, *miles*. The interaction term between the community-level mobile phone coverage and the community-level distance to the district center, *LC1mob*miles*, is also included to examine the combined effect of mobile coverage and distance to market. All the sample households are included, including those in areas never covered by the network.

The first model is on the mobile phone network coverage at the community level. We group the sample LC1s into three groups, as we do in Tables 7.2 and 7.3, and estimate the following model with the Multinomial Logit Model:

$$\Pr(LC1mob_j = y) = \beta_0 + Z_{jt}\beta_Z + \varepsilon_{jt}, \quad (7.2)$$

where the dependent variable is 0 if LC1 *j* was covered by the network already in 2003 (Y/Y group), 1 if LC1 *j* was not covered in 2003 but was covered by the network in 2005, and 2 if LC *j* was not covered by the network even by 2005, and Z_{jt} is a set of community characteristics of community *j*.

Next, we estimate the determinants of mobile phone possession at the household level:

$$\Pr(HHmob_{it} = 1) = \beta_0 + \beta_1 yr05_t + \beta_2 LC1mob_{jt} + X_{it}\beta_k + Z_{jt}\beta_l + \beta\alpha_i + \varepsilon_{it}, \quad (7.3)$$

Table 7.3 Determinants of mobile phone network coverage at the LC1 level (multinomial logit model: the base category is the LC1s with mobile phone coverage between 2003 and 2005)

	LC1s covered by mobile phone by 2003	Areas not yet covered by mobile phone in 2005
Distance from district center (miles)	-0.377 (1.68)	0.003 (0.05)
Speed from district center (miles/min)	-0.390 (0.44)	-4.69 (0.81)
Driving time from district center (min)	-0.002 (0.52)	0.002 (0.23)
LC1 level population density	0.001** (2.63)	0.000 (0.81)
Central region	0.878* (2.05)	-35.43 (0.00)
Western region	1.263** (2.74)	2.701** (2.54)
Year 2005	0.053 (0.16)	0.187 (0.24)
Constant	-0.352 (0.66)	-3.000 (1.61)
Number of observations	174	

Local Council 1 (LC1) is the lowest administrative unit in Uganda

Numbers in parentheses are absolute *t*-values

* Significant at 10%, ** significant at 5%, *** significant at 1%

where $t=2003$ and 2005 , X_{it} is a set of household characteristics of household i at time t , and α_i is time-invariant unobserved household and community characteristics. We estimate this model using Probit because the dependent variable is a binary variable, which takes one if the household possesses at least one mobile phone unit. Then, to estimate a more precise estimator of the impact of the mobile phone coverage at the community level, we estimate the same model with the household level fixed-effects (FE) model. By estimating the FE model, we eliminate any biases caused by the time-invariant unobserved household and community characteristics. While the effect of time-invariant unobserved household and community characteristics are eliminated, the FE model cannot control for the community characteristics that might have affected the order of mobile phone network expansion. Thus, we must note that we cannot eliminate biases caused by these community characteristics in relation to the placement of the mobile phone network.

On the determinants of market participation, we estimate the following model with the household FE-IV model:

$$\begin{aligned} \Pr(S_{it} > 0) = & \beta_0 + \beta_1 HHmob_{it} + \beta_2 LC1mob_{jt} + \beta_3 LC1mob_{jt} * miles_j \\ & + \beta_4 yr05_t + X_{it}\beta_k + Z_{jt}\beta_l + \alpha_i + \epsilon_{it}. \end{aligned} \quad (7.4)$$

Our hypotheses suggest that the estimated coefficients of the mobile phone variables would be positive on banana marketing. We also hypothesize that the impact is larger in areas farther away from the district center and, hence, the estimated coefficient of the interaction term between the mobile phone coverage and the distance from the district center (β_3) would be positive. Note that because farmers decide whether they sell their products by comparing their reservation prices and the farm-gate price, household characteristics are important determinants of market participation. Because we estimate the household-level FE model, however, the fixed household characteristics are excluded from the FE models. In addition, following the same estimation strategy, we estimate the function explaining the ratio of sales to production. Finally, we estimate a model on banana production income, which is the difference between the banana production value and the paid-out costs, which do not include the cost of unpaid family labor.

Regarding the independent variables, we use mostly community-level variables. First, we use the community-level mobile phone network coverage binary variable, *LC1mob*, which was asked during the village-level group surveys. As a result, we assume that all households in the same LC1 are covered by the mobile phone network at the same time.

With regard to roads, as much as 88% of the communities surveyed in 2005 responded that they were connected to the nearest district town by all season tarmac or dirt roads. In 2003, the corresponding number was 84%. When asked if it was possible to drive there, 97% of the communities responded that it was possible both in 2005 and 2003. This suggests that the road condition in the surveyed communities did not change much between 2003 and 2005. Thus, we use the 2003 distance, not the speed, from the community center to the district center in the analyses.

7.5 Results

As we show in Fig. 7.1, the mobile phone network was first established in the central and eastern parts of Uganda where the population density is high and the economy is advanced. Along the highway between western Kenya and Kampala, several industrial clusters, such as Jinja, are located. The results in Table 7.3 confirm our expectations, indicating that the probability of being covered by the mobile phone network in 2003 was higher in more populated and less remote areas. Obviously, the coverage of the mobile phone network is not random. Thus, it is possible that the network coverage is correlated with unobserved community characteristics, as we discussed in Sect. 7.4. To overcome this problem, we estimate the household FE model to control for not only the unobserved LC1 characteristics but also the unobserved household characteristics.

Next, we present the estimation results on the determinants of household mobile phone possession in Table 7.4. The Probit results suggest that the probability of possessing mobile phones increases by 2.3% points if the community is covered by the mobile phone network. The magnitude of the impact increases to 5.4 points when the household FE model is used. According to the FE model, the probability of possessing mobile phones also increases by 4.2 points in 2005 as compared to 2003. Among household characteristics, the total value of assets and the education level of both male and female household members increase the probability of possession significantly. The age of the household head has a negative impact, suggesting that households with younger heads have more interest in mobile phones. Note that we do not include these household characteristics in the FE model because these variables are initial household characteristics and fixed over time. Because these initial household characteristics do not belong to the FE models, we use them as instrumental variables when they are interacted with the mobile phone coverage dummy, which is time-variant. When the network covers a community, we expect that households with more assets and higher education levels are more likely to acquire mobile phones than those with fewer assets and lower education levels. Thus, in the following analyses, we use four interaction terms between the mobile phone coverage and four household characteristic variables.

The results in Table 7.5 suggest that the mobile phone possession increases the probability of banana sales by 20 percentage points. Although this result is based on the FE models and, hence, not biased by unobserved time-invariant household characteristics, it is still possible that it is biased by the unobserved time-varying household characteristics. When we apply the FE instrumental variables model, we find that the coefficient of the household mobile phone possession shrinks in magnitude to 0.15 and is no longer statistically significant. Thus, although the results in the table suggest that there is a positive association between household mobile phone possession and banana sales, the causal relation is not clear.

Regarding the community-level impact, the result in Table 7.5 indicates that the mobile phone network increases the probability of banana sales in remote areas: the

Table 7.4 Determinants of household mobile phone possession

	Household mobile possession with mobile coverage dummy	
	Probit	Household fixed effects
Year 2005 (=1)	0.027 (3.96)***	0.042 (4.08)***
Mobile coverage dummy	0.023 (3.29)***	0.054 (3.80)***
<i>Household characteristics</i>		
Size of household	0.001 (1.12)	
Number of male adults	-0.016 (1.60)	
Number of female adults	-0.004 (0.48)	
Number of boys	-0.002 (0.75)	
Number of girls	0.000 (0.04)	
Age of household head	-0.001 (4.67)***	
Gender of head (fem = 1)	-0.009 (0.81)	
Widowed household (yes = 1)	0.011 (1.65)*	
Education of male adults	0.004 (4.72)***	
Education of female adults	0.005 (5.93)***	
ln (land size)	-0.001 (0.42)	
ln (farm assets value)	0.013 (6.25)***	
Banana seller in 2003	-0.004 (0.72)	
Number of Observations	1,754	1,787

Coefficients are marginal changes in the probability

Numbers in parentheses are absolute *t*-values

* Significant at 10%, ** significant at 5%, *** significant at 1%

interaction term of the distance to the district center and the mobile phone coverage has a positive coefficient. The mobile phone network itself, however, has a negative coefficient and thus decreases the probability of banana market participation by 9.5 percentage points. As a result, the combined impact is negative near the district center and positive in remote areas. According to the results, the combined impact becomes positive at 12 miles away from the district center because the estimated coefficient of the interaction term indicates that banana sales participation increases

Table 7.5 Market participation and mobile phone coverage/possession

Variables	Pr (selling banana)			Ratio of sales quantity to production		
	FE	FE	FE-IV	FE	FE	FE-IV
Household mobile phone possession dummy ^a	0.203* (2.35)	0.209* (2.44)	0.151 (0.19)	0.118** (2.39)	0.121** (2.45)	-0.062 (0.14)
Community mobile phone coverage dummy	0.055 (1.57)	-0.095 (1.41)	-0.094 (1.11)	0.054*** (2.68)	-0.011 (0.29)	0.000 (0.02)
Distance to district center (miles) × mobile coverage		0.008*** (2.62)	0.007** (2.53)		0.003** (1.99)	0.003* (1.81)
Year 2005 (=1)	0.481*** (17.73)	0.502*** (17.84)	0.505** (10.85)	0.174*** (11.18)	0.183*** (11.31)	0.191*** (7.04)
F-stat on IVs			2.58			2.58
Number of observations	1,161	1,161	1,151	1,161	1,161	1,151

Numbers in parentheses are absolute *t*-values

The distance to the district center is not included in the models because it is fixed over time

* Significant at 10%, ** significant at 5%, *** significant at 1%

^aInstrumental variables: The household mobile possession (HHmobile) is instrumented by the four interaction terms between the mobile coverage dummy and the four household characteristics: log of farm equipments value, age of household head, education of male adult, and education of female adult. These IVs together passed the over-identification test at the 1% significance level

by 0.8% points as the distance from the district center increases by one mile (the 0.8% increase multiplied by 12 miles is about 9.6%). The results, therefore, suggest that the farther away the farmer is located from the district center, the larger the impact of the mobile phone coverage on market participation.

Because banana farmers in remote areas have lower costs of banana production in general, the mobile phone network may have favored the banana producers in remote areas over the banana farmers near the district centers. The result does not change much even after applying the instrumental variables (FE-IV), thus further supporting the same hypothesis. Some caveats should be applied to the results from the FE-IV model. Obtaining valid instrumental variables is difficult in general. Our instrumental variables are not strongly jointly correlated with the household mobile phone possession (*F*-statistic is 2.6). Thus, the results from the FE-IV model should be treated as robustness tests for the FE models. We have also estimated the same models in Table 7.5 by excluding household mobile phone possession and find similar results on the community-level mobile phone network. The results on the ratio of banana sales quantity to production are very similar to the results on market participation.

In summary, the results from the instrumental variables model in Table 7.5 show that the household-level mobile phone possession may not have a significant impact on banana market participation, but the community-level mobile phone network coverage has a significant impact in remote areas. The results, therefore, suggest that even those households that do not possess mobile phones benefit from the

network, possibly because traders use mobile phones to communicate with village representatives. As we mentioned before, as long as one person in a village has a mobile phone, the person can set up a time and place to collect banana and even negotiate possible prices with traders on behalf of fellow banana producers in the village. According to the surveys used in this study, most of the farmers in Uganda sell banana and maize to traders at the farm gate, and the proportion has slightly increased over time. These findings are consistent with Hypothesis 1.2, formulated in Chap. 1, that farmers respond to improved market conditions by producing more profitable crops.

Last, Table 7.6 shows the analysis of the banana production net value per household (“banana income”), where we can confirm a significant positive impact of the mobile phone network in remote areas.⁷ The results suggest that network expansion increases banana income in remote areas. Similar to the results in Table 7.3, the mobile phone network itself has a negative impact, but the interaction term with the distance from the district center has a positive coefficient. According to the results, the combined impact becomes positive at about 18.2 miles: 7,394 shillings multiplied by 18.2 miles is about 135,000 shillings, which is just over the estimated negative coefficient of the mobile phone network.

Table 7.6 Production income and mobile phone coverage/possession

Variables	Production income (Shs)			
	FE	FE	FE	FE-IV
Household mobile phone possession dummy ^a	−86,385 (1.04)	−93,333 (1.11)	−82,829 (0.97)	234,283 (0.49)
Community mobile phone coverage dummy	−134,851** (2.09)	−2,775 (0.08)	−42,664 (0.57)	−159,937** (2.16)
Distance to district center (miles) × mobile coverage	7,397** (2.45)		7,543** (2.48)	7,861* (2.49)
Land owned × mobile coverage			−84,316*** (2.65)	
Year 2005 (=1)	199,122*** (7.07)	182,141*** (6.65)	198,461*** (6.34)	187,251*** (5.25)
<i>F</i> -stat on IVs				9.52
Number of observations	1,503	1,503	1,482	1,482

Numbers in parentheses are absolute *t*-values

The distance to the district center itself is not included in the models because it is fixed over time.

The 2005 incomes are deflated to the 2003 price level

* Significant at 10%, ** significant at 5%, *** significant at 1%

^aInstrumental variables: The household mobile possession (HHmobile) is instrumented by the four interaction terms between the mobile coverage dummy and the four household characteristics: log of farm equipments value, age of household head, education of male adult, and education of female adult. These IVs together passed the over-identification test at the 1% significance level

⁷The 2005 values are deflated to the 2003 price level by using the consumer indices from the International Financial Statistics.

To further investigate who have benefited from the mobile phone network beyond distance, we have included an interaction term between the mobile phone network and household land size in the third column. The negative coefficient for the interaction term between mobile phone coverage and land owned suggests that the income increase was experienced by smaller landholders. This is possibly because large banana farmers might have had more long-term contact with traders even without mobile phones because they produced a large volume of banana, and possibly had more access to information through stronger social contact with a mobile phone owner. Thus, the potential marketing gain from mobile phones was small after the network expansion. This is an important hypothesis that requires further investigation.

7.6 Conclusion

Enhancing farmers' participation in markets is considered an important strategy to reduce rural poverty in Africa. This paper uses panel data from Uganda to test the hypothesis that mobile phone coverage expansion induces the market participation of farmers producing perishable crops such as banana in remote areas. Uganda has recently experienced a rapid expansion of areas covered by the mobile phone network. As information flow increases due to the expanded mobile phone coverage, the cost of crop marketing is expected to decrease, particularly in remote areas where potential marketing gains from the increased information flow is large. We indeed find that the network expansion has a larger impact on market participation in areas farther away from district centers than in nearby areas.

It is not clear, however, whether farmers obtain the full gain stemming from this reduction in marketing costs. To enable farmers to obtain the full potential gain, information asymmetry between traders and farmers needs to be eliminated, and farmers need to have access to alternative traders who are ready to pay a higher price. One route to eliminate this asymmetry is to strengthen the public dissemination of price information. For instance, one possible mechanism is to obtain and share timely price information through producer organizations that are equipped with mobile phones. In this setting, individual farmers do not need to possess mobile phones, and the representatives of producer organizations can negotiate prices with potential buyers and arrange transactions. This seems much more effective than individualized arrangements with traders. Indeed, the evidence in this paper suggests that in remote areas in rural Uganda, the expansion of mobile phone coverage itself, not necessarily mobile phone possession at the household level, has benefited farmers who produce perishable products.

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Part III
Soil Fertility and Emerging Agricultural
Innovations

Chapter 8

Optimal Fertilizer Use on Maize Production in East Africa

Tomoya Matsumoto and Takashi Yamano

Abstract We investigate the reasons for the low application of external fertilizers on farms in Kenya and Uganda. The results suggest that Kenyan maize farmers have applied inorganic fertilizer at the optimal level, corresponding to the high nitrogen-maize relative price, in one out of the two survey years and also responded to the price change over time. In Uganda, we find that even the low application of inorganic fertilizer is not profitable because of its high relative price. Policies that reduce the relative price of fertilizer could be effective in both countries, while the efficacy of policies based on improving farmers' knowledge about fertilizer use will be limited as long as the relative price of fertilizer remains high.

Keywords Maize • Fertilizer use • Crop production • Kenya • Uganda

8.1 Introduction

Although there have been many studies to explore the reasons behind the low application of the inorganic fertilizer, some competing hypotheses remain (Morris et al. 2007; Kelly 2006). A market-based hypothesis suggests that farmers are responding to the high fertilizer price, which has been the result of high transportation and marketing costs in Africa (Jayne et al. 2003; Gregory and Bumb 2006). As a result,

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farmers in East African countries are discouraged to apply inorganic fertilizer on staple crops such as maize. Nonmarket-based hypotheses emphasize farmers' lack of knowledge on inorganic fertilizer and high-yielding varieties (HYV), as well as financial constraints (surveyed in Morris et al. 2007). The lack of knowledge argument is less suitable in some African countries where many farmers have used inorganic fertilizer before, especially when it was heavily subsidized prior to the Structural Adjustment period. But it is still applicable in some countries, such as Uganda, where many farmers have never used inorganic fertilizer before. The financial constraint argument appears plausible in many African countries because most farmers remain poor. Even if farmers are knowledgeable about improved technologies, they may apply fertilizer only if it is subsidized. In fact, the case study in Chap. 4 in this book shows that a high inorganic fertilizer use in Ethiopia is due to a large-scale credit program. To draw effective policy implications, we need to identify the root causes of the low application of inorganic fertilizer on crop production in Sub-Saharan Africa (SSA).

In this chapter, we use 2-year panel data of farm households in Kenya and Uganda where we have maize production data on 6,329 plots. Kenya and Uganda provide an interesting comparison because Kenya has one of the highest maize productivities in Africa, while Uganda has one of the lowest (Smale and Jayne 2003; Sserunkuma 2005). We test if the marginal physical product (MPP) of inorganic fertilizer use is equal to the input–output relative price. If nonmarket constraints are root causes, then the MPP must be significantly larger than the relative price. According to the results of statistical analysis in this chapter, Kenyan maize farmers have applied inorganic fertilizer roughly at the optimal level on both the purchased HYV and local/recycled HYV maize.¹ In Uganda, even the low application of inorganic fertilizer is not profitable because of the high relative price of fertilizer. Thus, the results in this chapter are consistent with the market-based hypothesis, suggesting that given the currently available technology, the input–output price ratio has to be lowered to encourage farmers to use more inorganic fertilizer in Kenya and Uganda.

The chapter is organized as follows. Section 8.2 explains the household panel data used in this chapter. Section 8.3 describes a simplified theoretical model and discusses briefly estimation models.² Section 8.4 presents the estimation results on maize production in both countries. Finally, we discuss the policy implications in Sect. 8.5.

¹Many farmers in Kenya and Uganda recycle purchased HYV maize after harvesting. We group the recycled HYV maize with the local maize as we explain later in Sect. 8.2. Even the quality of the purchased HYV maize in Uganda is questionable. Some of the improved seeds in Uganda are open pollinated varieties. We discuss more on the issue in the chapter.

²Detailed discussions on the theoretical and estimation models are presented in Matsumoto and Yamano (2009).

8.2 Soil Fertility and Returns to Fertilizer on Maize

To estimate returns to fertilizer applications on maize production, we first consider pathways through which soil fertility contributes to crop production. Directly, soil provides nutrients to crops, and, indirectly, soil affects how easily external inputs are absorbed by the crops (Tiessen et al. 1994; Palm et al. 2001; Bationo and Mokwunye 1991). As a proxy for soil fertility, Marennya and Barrett (2007) use the carbon content. The soil carbon content (SCC) is also a proxy for soil organic matter (SOM), which consists of the decayed tissues of plants and animal excreta and is increasingly taken as a strong indicator of soil fertility and land degradation because SOM tightly controls many soil properties and major biogeochemical cycles (Ngugi et al. 1990; Manlay et al. 2006).

Soil characteristics are not fixed over the long run. Organic manure (whether from animals or plants), for instance, can directly alter soil characteristics. Thus, the impacts of sustained organic manure application have a long-term impact on crop production through changing the soil characteristics. Thus, current soil characteristics reflect the past applications of organic manure to some extent. In the following analysis, therefore, we consider the organic manure application as a flow variable and the SCC as a stock variable.

Regarding the shifter of the production function, we consider a soil nutrient indicator. Let us denote N_{pit} as the soil nutrient indicator of plot p of household i at time t :

$$N_{pit} = N(E_t, C_{pit}, O_{pit}), \quad (8.1)$$

where E_t is the basic soil condition, such as the soil carbon content, assumed to be time-invariant for a short time period; C_{pit} is the quantity of the inorganic fertilizer application (kg/ha), and O_{pit} is the quantity of the organic manure application (ton/ha). We assume that the basic soil condition, E_t , is common across the maize plots within a household and fixed over several years. We use the SCC as a single indicator of the soil condition in the following analyses by following Marennya and Barrett (2007).³

For the production function, we consider a simple yield function of the Cobb-Douglas form. The yield, kilograms per ha, denoted by Y_{pit} , is given as follows:

$$Y_{pit} = A_i I_{pit}^{\beta_L} S_{pit}^{\beta_S} N_{pit}^{\beta_N} e^{\omega_{pit}}, \quad (8.2)$$

³As we discuss in Sect. 8.3, we have only one soil observation per household. Thus, we assume that the soil carbon content is fixed across maize plots within a household and over time. Although it is not clear how long the soil carbon content is stable over time, it seems that the soil carbon content is more stable than other soil nutrients, such as nitrogen content.

where L_{pit} is the plot size (ha), S_{pit} is the seed quantity planted (kg/ha), A is the Hicks neutral technology parameter or the total factor productivity.⁴ We assume that A is time-invariant at least for the short time period of 2–3 years. ω is assumed to capture a productivity shock affected by weather conditions or other idiosyncratic factors. By taking logs of the yield function (2), we have

$$y_{ipt} = a_i + \beta_L L_{ipt} + \beta_S S_{ipt} + \beta_N n_{ipt} + \omega_{ipt}, \quad (8.3)$$

where the lowercase variables represent the log of their corresponding uppercase variables. The functional form of the nutrient indicator given by Eq. 8.1 is unknown but we take a second-order approximation of the log of N so that it captures the interaction effects of the external inputs and the SCC. We expect that the interaction terms between the SCC and the external inputs have positive impacts on the crop production.

The simple OLS regression of y on the observables with pooled samples, however, may provide biased estimates. First, the unobservable total factor productivity, a_i , could be correlated with the inputs. Fortunately for us, we have panel data. Thus, by estimating the fixed-effects (FE) model, we can at least remove the effects of the time-invariant unobserved factors, although we cannot identify the coefficients of the time-invariant independent variables in the FE model. Another issue to be considered is the correlation of the productivity shock with the input variables. Specifically, rainfall would be correlated with input use and yield simultaneously because the agriculture production in our survey regions is predominantly rain-fed, and farmers determine the level of input use according to the amount of rainfall. In this study, this issue is dealt with by introducing time–region dummies as covariates. With this treatment, we can control for other region level time-variant factors as well.

8.3 Data and Descriptive Analysis

8.3.1 Data

The data used in this chapter come from household-level panel surveys in Kenya and Uganda, collected as part of the Research on Poverty and Environment and Agricultural Technology (RePEAT) Project. All surveys employ comparable

⁴We do not include family labor in the model because family labor input was not asked in the second round of the surveys in both Kenya and Uganda. The family labor module was removed from the questionnaire in the second round because the quality of the family labor information was considered poor in the first round of the surveys. We implicitly assume that family labor input is adjusted optimally when the other input levels change. In the regression models, we estimate the household fixed effect models. Thus, as long as the family labor input remains at the same level, the omission of the family labor may not cause a serious bias.

questionnaires across countries and time. In addition, soil samples were collected from maize fields when the first rounds of the surveys were conducted. The surveys in Kenya were conducted in 2004 and 2007. The first round of the surveys covered 899 randomly selected households located in 100 sub-locations scattered in central and western regions of Kenya.⁵ In the second round, seven sub-locations in Eastern province were dropped because of the scale reduction of the survey project. Thus, in this chapter, we drop the samples from Eastern province in Kenya for the analysis below since we apply statistical methods relying on the longitudinal aspects of the data. In addition, attrition also reduced the number of households interviewed. As a result, out of the 777 targeted households, 725 households were revisited for the survey, resulting in an attrition rate of 6.7%.⁶

The surveys in Uganda cover 94 rural Local Council 1 (LC1)s that are located across most regions in Uganda, except the North where security problems exist.⁷ From each rural LC1, 10 households are randomly selected, resulting in a total of 940 small farm households. The second round was conducted in 2005, and 895 households out of the 940 original households visited in the first round were interviewed. Thus, the attrition rate was low at 4.8%.⁸

Along with the first round of the surveys in Kenya and Uganda, we collected soil samples from the largest maize plot or one of the other cereal plots if maize was not cultivated at each sample household. If no cereal crops were cultivated by a household, no soil samples were taken. The soil samples were collected at a depth of 0–20 cm from five different positions within each plot of a sample household and mixed. Later, the samples from Kenya and Uganda were sent to the soil laboratory at the World Agroforestry Center (ICRAF) in Nairobi and were tested by a new method called near-infrared reflectance spectroscopy (NIRS), following protocols developed by Shepherd and Walsh (2002) and Cozzolino and Morton (2003).

We have matched the soil information to 77% of the maize plots in Kenya and 67% of the maize plots in Uganda. The major reason for not having the soil information on some of the maize plots is simply because some soil samples were either lost or spoiled before being tested in the laboratory. Because the soil samples were collected at the time of the first survey, we do not have soil information on the maize plots of households that did not produce maize or any other cereals in the first round of the surveys. The Probit regression models for the soil sample attrition indicate

⁵These two waves of surveys in Kenya were conducted by Tegemeo Institute, with financial and technical help from National Graduate Institute for Policy Studies (GRIPS).

⁶We estimated the determinants of the attrition from the surveys and found that none of the independent variables is significant at the 5% level. Thus, we think that the attrition mostly occurred randomly and do not expect serious attrition biases.

⁷The surveys in Uganda were conducted jointly by Makerere University, Foundation for Advanced Studies on International Development (FASID), and National GRIPS.

⁸The attrition rate is less than 5%. None of the independent variables in the determinants of the attrition model is significant even at the 10% level. Thus, we do not think the attrition biases serious.

that most of the household variables are not correlated with the attrition. The major determinants of the soil sample attrition are the region dummies, which represent the soil sample losses and spoilages. Thus, we do not think that the soil sample attrition is systematically correlated with the household characteristics to create attrition biases. In addition, because we estimate the household FE models, we think that if any attrition biases exist, they would be small.

8.3.2 *Maize Yields in Kenya and Uganda*

Farmers in Kenya and Uganda cultivate local, high-yielding hybrid, and improved open-pollinated variety (OPV) maize. Because maize is a highly cross-pollinated crop, farmers cannot maintain the quality of the high-yielding hybrid variety from on-farm seed multiplication. In the case of improved OPV, farmers can maintain the quality of the seeds if they take proper care of isolating the OPV maize plots from other maize plots. It is, however, very difficult to do so because most farmers have small plots in highly cultivated areas. Yet, in both countries, farmers practice on-farm seed multiplication of HYV and OPV seeds. As a result, the recycled or self-produced HYV and improved OPV seeds have low yields. Indeed, we find that the recycled HYV seeds, which include improved OPV seeds, have yields that are comparable with local seeds. Note that we do not distinguish improved OPV seeds from HYV seeds because our respondents are unable to do so. Thus, we combine improved OPV seeds with HYV seeds in this chapter. For simplicity, we refer to the newly purchased HYV and OPV seeds as “purchased HYV maize” and the local and recycled HYV and OPV seeds as “local maize.”

In Fig. 8.1, we show the average maize yields in 2004 and 2006 in Kenya and Uganda. In this figure, we find that the average yield of purchased HYV maize is above 2 ton/ha in Kenya, while the average yield of local HYV maize is about 1.4 ton/ha. Thus, the average yield of purchased HYV maize is about 43% higher than that of local maize. In Uganda, the difference between purchased HYV and local maize is very small: the average yield is just above 1.5 ton/ha for the HYV maize, while it is 1.4 ton/ha for local maize. Thus, the difference is merely 13%. The low yield of purchased HYV maize in Uganda is partly due to poor quality of the HYV maize, which includes open-pollinated seeds.

In addition, the low yield of the purchased HYV maize in Uganda could be due to the negligible use of inorganic fertilizer. In Table 8.1, we compare maize production and input use between Kenya and Uganda. The adoption of purchased HYV is about 59% in Kenya, while it is 21% in Uganda. As expected from Fig. 8.1, the average maize yield is higher in Kenya than in Uganda. In Kenya, the average yield is about 2.0 ton/ha, while it is 1.5 ton/ha in Uganda. The difference between the two countries is partly due to the differences in application of inputs. For instance, 74% of maize plots receive at least some inorganic fertilizer in Kenya, while only 3% of maize plots do so in Uganda. It has been widely believed that the low use of inorganic fertilizer in Uganda is due to the better soil in Uganda than in Kenya. We find

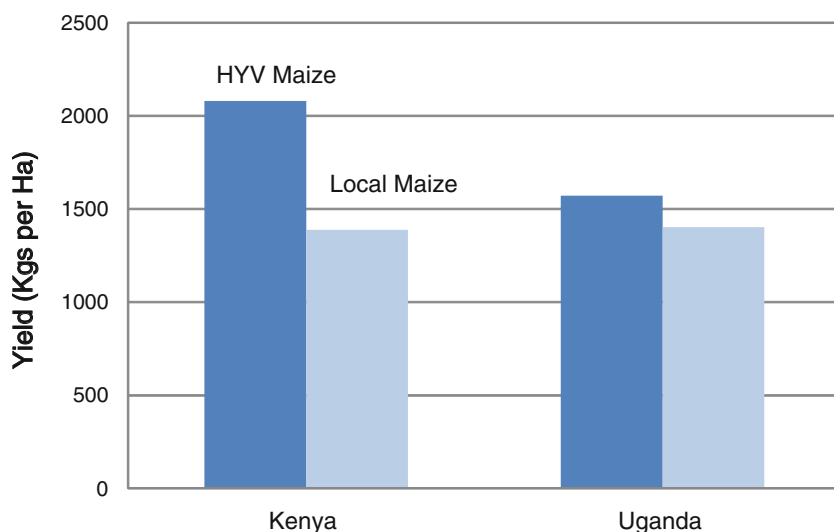


Fig 8.1 Maize yields in Kenya and Uganda by seed type (*Note: The recycled HYV seeds are grouped together with the local seeds. The yield distribution of the recycled HYV seeds has a similar distribution to the local seeds rather than the purchased HYV seeds*)

Table 8.1 Maize production characteristics in Kenya and Uganda

	Kenya (1)	Uganda (2)
Maize yield		
Yield (kg/ha)	1,986	1,541
Seed type		
Hybrid seeds use (ratio)	0.59	0.21
Input use		
Proportion of chemical fertilizer used	0.74	0.03
Chemical fertilizer use (kg/ha)	94.7	2.4
Proportion of organic fertilizer used	0.50	0.06
Organic manure use (kg/ha)	1,935	86
Soil characteristics		
Carbon content (%)	2.48	2.35
pH	6.15	6.64
Number of plots	3,131	3,198

The recycled HYV seeds are grouped together with the local seeds. The yield distribution of the recycled HYV seeds has a similar distribution to the local seeds rather than the purchased HYV seeds

in Table 8.1, however, that this is based on a false premise. Among the maize plots with soil data, we find that the average carbon content is 2.5% in Kenya and 2.4% in Uganda.

One of the most striking differences between the two countries is the maize price (Table 8.2), as Chaps. 2 and 4 in this book discuss in detail. The maize price in

Table 8.2 Input and output prices on maize in Kenya and Uganda

	Maize price	DAP price		Nitrogen price ^a	
	(1)	(2)	(3)	(4)	(5)
	USD/100 kg	USD/100 kg	DAP/maize	USD/100 kg	N/maize
Kenya					
Wave 1 (2004)	16.7	40.3	2.4	223.9	13.4
Wave 2 (2007)	17.8	51.2	2.9	284.4	16.0
Uganda ^b					
Wave 1 (2003)	9.4	38.2	4.1	212.2	22.6
Wave 2 (2005)	8.8	59.4	6.7	330.3	37.5

^aNitrogen price is calculated by dividing the DAP price by 0.18, which is the ratio of nitrogen content in DAP

^bEastern region only

Uganda is about half of the maize price in Kenya: it is \$9 per 100 kg in Uganda, while it is \$17 or 18 per 100 kg in Kenya. On the other hand, the fertilizer price in Uganda is about the same as in Kenya. This is probably because Ugandan farmers who use fertilizer live near the border to Kenya and buy it from the Kenya market. The fertilizer price would undoubtedly be much higher in central and western Uganda, but we do not have price information in these areas because no maize farmers among our samples use inorganic fertilizer. As a result of the low maize price in Uganda, the DAP–maize relative price in Uganda is about 4.1 in 2003 and 6.7 in 2005, which were more than double the ratio in Kenya, which were 2.4 in 2004 and 2.9 in 2007. The Kenyan relative price is still fairly high by international standards, but the Ugandan relative price is very high by international standards. Thus, it is understandable that the inorganic fertilizer application is low in Kenya and very low in Uganda. In the following sections, we investigate if the high input–output relative prices in Kenya and Uganda explain the low inorganic fertilizer applications in the two countries.

Maize farmers in Kenya and Uganda mainly apply two kinds of inorganic fertilizers, DAP and urea. To identify the MPP of each kind of the inorganic fertilizers would be difficult. Thus, we convert amounts of different kinds of inorganic fertilizers into their nitrogen content. For instance, 100 kg of DAP contain 18 kg of nitrogen. Thus, by applying 0.18 to the amount of DAP applied, we can obtain the nitrogen equivalent of the DAP application. This can then be added to nitrogen equivalents of other kinds of the fertilizer applications. The same logic can be applied to convert the DAP price to a price of a kilogram of nitrogen (by dividing the DAP price by 0.18). Finally, the relative price of nitrogen to maize can be calculated, and these are presented in Table 8.2. In Kenya, the nitrogen–maize relative price is 13.4 in 2004 and 16.0 in 2007. It is 22.6 in 2003 in Uganda and 37.5 in 2005. Because we estimate the MPP of the nitrogen in each country, it is the nitrogen–maize relative price that would be compared with the estimated MPP from the estimation models.

8.4 Optimality of Nitrogen Fertilizer Application

If maize farmers apply inorganic fertilizer at the optimal level, then the MPP of inorganic fertilizer should be equal to the input–output price ratio. If other constraints are holding the applications low, then the MPP should be larger than the input–output price ratio. To test this hypothesis, we estimate the maize yield function and identify the MPP for the two countries. Maize farmers in the two countries plant both improved maize seeds, which are mostly hybrid seeds in Kenya but are mixed of hybrid and open-pollinated seeds in Uganda, and local maize seeds. We expect that the MPP of the improved seeds is different from the MPP of local maize seeds. Thus, we estimate the yield function separately for the improved and local maize seeds by using the endogenous switching model, while controlling for household fixed effects.

Input applications in yield models are considered as endogenous variables because the input variables are most likely to be correlated with unobserved household and plot characteristics. Such correlations create biases in the estimated coefficients. We mitigate this problem by controlling for household fixed effects by using panel data. Thus, we can at least control for time-invariant household characteristics, such as ability of farmers.

We also control regional level shocks by including interaction variables between region and time dummies. Although it is still possible for unobserved individual- and plot-specific shocks to be correlated with the input variables, we believe that we can obtain reliable estimators. We provide much more detailed discussions of the estimation models in Matsumoto and Yamano (2009).

After estimating the yield function for each maize seed type for each country, we calculate the MPP by multiplying the average maize yield with the partial derivative of the nitrogen application evaluated at the means:

$$\text{MPP}(\text{kg} / \text{kg})_t^j = \bar{Y}_t^j \times E \left[\frac{\partial \ln(Y_t^j)}{\partial \text{Nitrogen}(100\text{kg})_t} \right] / 100, \quad (8.4)$$

and conduct a test to see if the MPP is equal to the relative price. By reviewing numerous technical studies by agricultural scientists, Yanggen et al. (1998) report that the typical yield response rate, which is the additional output obtained in kg divided by the additional nitrogen applied, is 17 in East and Southern Africa. In Kenya, Mbata (1997) reports response rates of 12–18 in Central and Western Kenya. Note that the Kenyan nitrogen-maize relative prices, 13.4 and 16.0, that we report in Table 8.2 are within the response rate range found in Mbata (1997). This consistency suggests that our relative price estimates are reliable and that the levels of the relative prices in Kenya are comparable to the response rates. In contrast, the relative prices in Uganda, 22.6 and 37.5, are much larger than the response rates found in Mbata (1997). Thus, it is understandable that farmers in Uganda do not apply inorganic fertilizer on maize. We present the regression results in the next section and examine this issue using our large panel data set.

8.5 Regression Results

8.5.1 Maize Yield

We present the results from the yield model separately for the OLS model (Table 8.3) and the semiparametric endogenous switching model (Table 8.4). In each table, we present the results for the local and HYV maize separately for each country.

Table 8.3 Determinants of log of maize yield: OLS model

	Kenya		Uganda	
	Newly purchased HYV plots	Local/ recycled HYV plots	Newly purchased HYV plots	Local/ recycled HYV plots
	(1)	(2)	(3)	(4)
ln (maize plot size in ha)	-0.2578 (8.60)***	-0.2980 (8.16)***	-0.1700 (2.97)***	-0.1550 (5.56)***
ln (seed kgs/ha planted)	0.3803 (7.75)***	0.3554 (7.49)***	0.6203 (10.76)***	0.6071 (23.09)***
ln (carbon content)	0.4568 (2.30)**	1.0130 (5.60)***	-0.0723 (0.21)	0.1445 (1.02)
ln ² (carbon content)	-0.0696 (0.78)	-0.2901 (3.08)***	-0.0726 (0.35)	0.0392 (0.58)
Nitrogen content of chemical Fertilizer input (100 kg/ha)	1.3971 (4.33)***	1.6396 (4.01)***	0.1469 (0.03)	-7.582 (0.82)
Nitrogen ²	-0.5735 (3.09)***	-0.3037 (1.10)	3.7317 (0.80)	0.8901 (0.36)
Organic manure (ton/ha)	-0.0066 (0.48)	0.0657 (3.05)***	0.9868 (1.28)	-0.1206 (0.45)
Organic ²	-0.0004 (1.56)	-0.0019 (3.22)***	-0.0468 (0.43)	0.0077 (0.30)
Nitrogen × ln (carbon content)	-0.4130 (1.65)*	-0.5494 (1.53)	1.2016 (0.30)	11.255 (1.00)
Organic × ln (carbon content)	0.0268 (2.32)**	0.0214 (1.21)	-0.9244 (1.78)*	0.1687 (0.68)
Nitrogen × organic	0.0047 (0.46)	-0.0930 (3.27)***	-17.705 (0.73)	
Constant	4.2312 (24.52)***	3.5159 (21.95)***	5.0469 (24.48)***	4.6093 (43.12)***
Observations	2,371		2,084	
$E[\text{maize yield (kg/ha)}]$	2,065	1,391	1,572	1,403
$E[\partial \ln Y / \partial \ln \text{Carbon}]^a$	0.32**	0.57**	-0.20	0.23**
$E[\partial \ln Y / \partial \text{Nitrogen}]^a$	0.81**	1.03**	0.20**	0.92
$E[\partial \ln Y / \partial \text{Organic}]^a$	0.019*	0.025**	-0.41	0.007

Absolute value of t statistics in parentheses

* Significant at 10%; ** significant at 5%; *** significant at 1%

^aThe significance level attached to the mean value corresponds to the test statistic for the joint test of the related coefficients being equal to zero simultaneously

Table 8.4 Determinants of log of maize yield: FE endogenous selection model^a

	Kenya		Uganda	
	Newly purchased HYV plots	Local/recycled HYV plots	Newly purchased HYV plots	Local/recycled HYV plots
	(1)	(2)	(3)	(4)
ln (maize plot size in ha)	-0.3512 (6.87)***	-0.4218 (6.29)***	-0.2886 (2.84)***	-0.2996 (5.72)***
ln (seed kg s/ha planted)	0.4092 (4.79)***	0.4321 (5.49)***	0.5891 (5.14)***	0.4848 (9.23)***
Nitrogen content of chemical Fertilizer input (100 kg/ha)	0.5926 (0.95)	2.0820 (3.44)***	3.0635 (0.67)	-19.9570 (0.01)
Nitrogen ²	-0.0921 (0.24)	-0.7703 (1.45)	-0.5241 (0.02)	2.3248 (0.00)
Organic manure (ton/ha)	0.0383 (1.88)*	0.0751 (2.24)**	1.5585 (0.16)	-0.0612 (0.18)
Organic ²	-0.0005 (1.12)	-0.0015 (1.25)	-1.1731 (0.15)	0.0323 (0.54)
Nitrogen × ln (carbon content)	0.3497 (0.84)	-0.9179 (1.39)	-1.7808 (0.44)	28.0156 (0.02)
Organic × ln (carbon content)	-0.0004 (0.03)	0.0047 (0.17)	-0.4270 (0.04)	0.0934 (0.33)
Nitrogen × organic	-0.0116 (0.63)	-0.0590 (1.06)	-20.394 (0.01)	
Region × season × year dummies	Included	Included	Included	Included
Observations	1,165	773	356	1,461
Number of households	356	220	112	366
R-squared	2,080.2	1,387.5	0.34	0.40
$E[\text{maize yield (kg/ha)}]$	2,080	1,388	1,572	1,403
$E[\partial \ln Y / \partial \text{Nitrogen}]^b$	0.82**	1.13**	1.35	0.80
$E[\partial \ln Y / \partial \text{Organic}]^b$	0.022*	0.041*	0.36	0.010

Absolute value of *t* statistics in parentheses

* Significant at 5%; ** significant at 1%

^aHouseholds with less than two observations are excluded from the regression

^bThe significance level attached to the mean value corresponds to the test statistic for the joint test of the related coefficients being equal to zero simultaneously

While the OLS results present simple regression results, ignoring the seed selection problem and the omitted household characteristics problem, the switching model controls for the household fixed effects as well as the selection between the purchased HYV and the local/recycled HYV maize. Because the SCC is fixed over time, we can only include the variable in the OLS model, although interactions terms of it with other time-varying variables remain in the switching model. Since we interact the SCC (measured in the natural log), the nitrogen content of the inorganic fertilizer (100 kg/ha), and the organic manure application (ton/ha) with each other and include also the squared terms, interpretations of the results could be complicated.

Thus, at the bottom of the tables, we present the partial derivative of each input evaluated at its mean. We also indicate if the partial derivatives are jointly significant.

Regarding the SCC, the results from the pooled OLS model suggest that the SCC has a positive impact on the maize yield with a decreasing return on both of the seed types in Kenya (Table 8.3). The elasticity evaluated at the means is about 0.32 for the purchased HYV maize, while it is about 0.57 for the local/recycled HYV maize. Because the average carbon content levels are about the same for the two seed types, according to the HYV adoption model in Table 8.1, the results suggest that the local/recycled HYV maize has a greater physical responsiveness to the SCC than the purchased HYV maize. The impact of organic manure is also greater on the local/recycled HYV maize than on the purchased HYV maize.

According to the endogenous switching model presented in Table 8.4, the average impact of an additional 1 ton of organic manure application per ha increases the maize yield by 4.1% for the local/recycled HYV maize and 2.2% for the purchased HYV maize. The estimated coefficients are robust across the estimation models. Thus, it seems that the local/recycled HYV maize is more physically responsive to organic matter, i.e., the SCC and organic manure, than the purchased HYV maize. The sizes of the estimated impacts of the organic manure may seem small. But note that the estimated coefficients of the organic manure could be biased toward zero because of the possible attenuation biases created by the measurement errors in the organic manure variables. This is because it is difficult to measure the quantity of applied organic manure. Farmers may not remember clearly how much organic manure they applied. In addition, the quality of organic manure varies from one farmer to another as it depends on the contents and how it is prepared. Thus, we should treat the estimated average impact of organic manure as a conservative estimate.

As expected, we find significant impacts of inorganic fertilizer on maize yield in Kenya, even though the individual coefficients are not significant (Table 8.4). As we present at the bottom of the table, the evaluated average impacts of the nitrogen content of inorganic fertilizer, measured in 100 kg/ha, is 0.82 for the purchased HYV maize and 1.13 for the local/recycled HYV maize, both of which are significant. Because of the decreasing return to inorganic fertilizer application, the smaller impact on the purchased HYV maize yield than the local/recycled HYV maize yield could be explained partly by the larger quantity of the nitrogen application on the purchased HYV maize than on the local/recycled HYV maize. The average nitrogen application on purchased HYV maize is about 17.9 kg/ha, while the average nitrogen application on local/recycled HYV maize is about 9.8 kg/ha. To investigate the optimality of the different application rates, we need to compare the MPP with the relative fertilizer price. We do so in Table 8.5, together for Kenya and Uganda.

We do not find any significant impacts, either individually or jointly, of the organic manure and inorganic fertilizer amounts on maize yield in Uganda (Table 8.4). This is not surprising because of the very low applications of both types of nutrients. As we show in Table 8.1, only 3% and 4% of the maize plots in Uganda received inorganic fertilizer or organic manure, respectively. In addition, as

Table 8.5 Relative prices and marginal returns of nitrogen application

	Marginal physical product (MPP) ^a	Average relative price (RP)	Test statistics if MPP=RP
	(1)	(2)	(3)
Kenya – wave 1			
Purchased HYV maize	14.10** (0.60)	13.4	$t=1.17$
Local/recycled HYV maize	11.05** (0.91)	13.4	$t=-2.59***$
Kenya – wave 2			
Purchased HYV maize	19.89** (0.67)	16.0	$t=5.77***$
Local/recycled HYV maize	16.13** (0.87)	16.0	$t=0.15$
Uganda – wave 1			
Purchased HYV maize	23.44 (1.68)	22.3	$t=0.68$
Local/recycled HYV maize	20.78 (10.80)	22.3	$t=-1.88^*$
Uganda – wave 2			
Purchased HYV maize	24.96 (4.70)	33.7	$t=-0.14$
Local/recycled HYV maize	25.23 (9.37)	33.7	$t=-0.90$

Numbers in parentheses are standard errors

* Significant at 5%; ** significant at 1%. The * and ** in column (1) indicate that the estimated coefficients for the evaluated MPPs are jointly significant in Tables 8.4 and 8.5. The *, **, and *** in column (3) indicate that the MPP and RP are statistically different

^aMPP = $E[Y^* \partial \ln Y / \partial \text{Nitrogen} | \text{HYV/non-HYV}]$, where Y is maize yield per ha

we discussed earlier, the quality of purchased HYV seeds is in question. Some HYV seeds may be actually OPV seeds whose productivity could have deteriorated. Thus, even if the Ugandan farmers had applied more inorganic fertilizer, the returns may not have been high.

8.5.2 Optimal Nitrogen Use

In Table 8.5, we find that the MPP of nitrogen varies from 11 to 20 in Kenya and 21 to 25 in Uganda. Compared with the estimates of the previous studies, these estimates are within a reasonable range. The MPP is 14 for purchased HYV during the first wave of the panel surveys in Kenya. The nitrogen-maize relative price is 13 during this period. The t -test indicates that the MPP is not different from

the relative price, suggesting that the nitrogen application is roughly at the optimal level for purchased HYV maize during this period in Kenya. For the local/recycled maize, the MPP is lower than the relative price, suggesting a slightly over-application of the nitrogen. During the next survey period, the results are the opposite. We find an almost optimal application on the local/recycled HYV maize but a slight under-application for the purchased HYV maize. Because of unexpected events, both agroecologically and economically, it is not surprising that Kenyan farmers miss the optimal application levels occasionally. It is more important to point out that the MPPs move in the same direction as the relative price over time. From the first to the second wave, the relative price increased from 13 to 16 and the MPPs of the purchased and local/recycled HYV maize also increased from 14 to 20 for the purchased HYV maize and from 11 to 16 for the local/recycled HYV maize. Thus, the results indicate that the Kenyan farmers are responding to the change in the relative price and successfully achieving the near optimal application level in one of the 2 years for both the purchased and local/recycled HYV maize. This strongly supports Hypothesis 2 that farmers respond to market conditions.

The relative price is much higher in Uganda than in Kenya: it is 22 and 34 in the first and second wave, respectively. Because of the low use of the nitrogen fertilizer in Uganda, the MPPs are not precisely estimated. Despite the low precision, we find that the MPP on the purchased HYV maize during the first wave is 23, which is close to the relative price at 22. During the second wave in Uganda, the MPP is around 25 for both the purchased HYV and local/recycled HYV maize, when the relative price is 33. Thus, assuming a decreasing marginal return, even the low application of the nitrogen fertilizer is not profitable. The relative price in Uganda is simply too high to apply inorganic fertilizer. The high relative price in Uganda is mostly because of the low maize price in Uganda, which is about 60% of the Kenyan price. Because it would cost more to send inorganic fertilizer from eastern Uganda to central and western Uganda, the potential relative price would be even higher in these regions. Thus, to decrease the relative price, the maize price would have to increase in this country, in addition to decreasing the inorganic fertilizer price. Otherwise, the relative price remains too high for any farmers to apply inorganic fertilizer.

8.6 Conclusions

To dramatically improve the maize productivity in SSA, the current level of external fertilizer application is considered to be too low. To investigate the reasons for the low external fertilizer application on maize, we have estimated the maize yield function in Kenya and Uganda in this chapter. By comparing the MPP of the nitrogen application on the maize yield and the nitrogen-maize relative price, we find that the Kenyan farmers have actually applied the economically optimal nitrogen application level in at least one of the two survey years on both the purchased and local/recycled HYV maize. We also find that Kenyan farmers have responded to the relative price

change over time. Thus, the results suggest that a market-based approach, such as reducing the inorganic fertilizer price or increasing the maize price or both, would be effective in encouraging farmers to use more inorganic fertilizer in Kenya.

In Uganda, we find that the yield of even newly purchased HYV maize seeds is low. This could be due to the very low application of inorganic fertilizer; only 3% of the maize plots are applied inorganic fertilizer. In addition, the low yield of the HYV seeds could be due to the poor quality of the seeds in this country. As we discuss in this chapter, some of the seeds identified as HYV seeds in Uganda could in fact be open pollinated seeds. The poor quality of the HYV seeds, which would have only low response rates to inorganic fertilizer, may discourage farmers to use inorganic fertilizer. Thus, to encourage Ugandan farmers to apply more inorganic fertilizer, the quality of improved seeds has to be improved and it must be guaranteed in the seed market. Given the currently available seeds, because of the very high relative fertilizer price, the results in this chapter suggest that no application of inorganic fertilizer is rational in Uganda. The maize output price is too low to cover the inorganic fertilizer costs. The maize output price in Uganda can be raised if the Uganda maize market is fully integrated with the Kenyan maize market, as Chap. 2 in this book discusses. In both Kenya and Uganda, the potential success of a nonmarket approach, such as credit or extension provision, would be limited as long as the relative price remains at the present level.

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Chapter 9

Dairy–Banana Integration and Organic Manure Use in Uganda

Takashi Yamano

Abstract An intensive dairy and crop farming system found in the East African highlands provides manure and urine, taken from stalls of improved dairy cattle, for crops such as banana. By using panel data of 894 rural households in 2003 and 2005 in Uganda, we find that the number of improved cattle per ha increases the organic fertilizer application on banana plots by 218 kg/ha. Regarding the banana yield, we find that 1 ton of the organic fertilizer per ha increases the banana yield by 10%, and a one percentage point increase in the soil organic matter (SOM) increases the banana yield by 7%. Because the organic fertilizer application improves the SOM in the long run, it has a long-term impact on the banana yield.

Keywords Organic fertilizer • Improved cattle • Production intensification • Banana • Uganda

9.1 Introduction

International prices for inorganic fertilizer have increased significantly in 2007 and in the first half of 2008, but dropped to their previous levels in the second half of 2008. Many experts believe that the fertilizer price will rise in the future as the demand for fertilizer increases. Increased inorganic fertilizer prices are likely to reduce the already low inorganic fertilizer application in Sub-Saharan African (SSA) countries. It is, therefore, natural for farmers and policy makers to turn their

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attention to alternative agricultural technologies that use less inorganic fertilizer. The particular technology that we focus on in this chapter is a mixed farming system of intensive dairy and crop farming, which is adopted by many farmers in the East African highlands (Otsuka and Yamano 2005). This farming system is based on the use of organic manure generated from the manure and urine of improved dairy cattle, i.e., crossbreeds of European and local cattle, which are often raised in stalls. It is easy for farmers to feed and milk dairy cows in stalls; at the same time, it is easy for them to collect manure and urine from stalls.

The need for organic manure application is acute in Uganda, as well as in other SSA countries, where land degradation is a serious concern (Smaling et al. 1997; Koning and Smaling 2005; Pender et al. 2006). Uganda has some of the best soils in East Africa but has one of the highest soil nutrient losses among SSA countries because of the low use of external fertilizers (Henao and Baanante 2006). Long-term experimental studies show that continuous cultivation using low external inputs decreases soil fertility and crop yields. A combination of inorganic fertilizer and organic manures is necessary to sustain and improve crop production on depleted soils (Bationo et al. 1998; Bekunda et al. 1997). Because organic manure is usually generated internally within a farming system, the total amount of soil nutrients does not increase within the system unless there is biological nitrogen fixing, recycling of nutrients in soil depths, or importation of external resources (e.g., feeds for livestock) (Buresh 1999). Soil scientists show that nitrogen efficiency could also be improved significantly by improving farm management at various steps starting from livestock feeding to crop harvesting (Rufino et al. 2006). Although there have been some economic studies on crop–livestock farming systems in the past (e.g., McIntire et al. 1992; Baltenweck et al. 2004), none of the previous studies has identified the causal impacts of adopting an intensive dairy system on farming system integration and crop production at the micro-level by using panel data.

The purpose of this study, therefore, is to identify the causal impacts of adopting an intensive dairy on farming system integration, organic manure application, and crop production. In particular, we examine banana production in Uganda by using panel data of 894 rural households, interviewed in 2003 and 2005. We also use soil fertility data taken from the 894 households. Banana is the most important staple crop and food in Uganda, yet it is one of the so-called “orphan crops” that have been mostly neglected by international research institutions (Naylor et al. 2004; Smale and Tushemereirwe 2007). Organic manure is often used to amend soils for banana before planting. Because organic manure releases nitrogen over time during the long growing cycle of banana and improves the soil structure to increase water retention, the use of organic manure on banana provides much needed nutrients to the soil, which is considered to have been depleted seriously over time in Uganda.

The outline of the chapter is as follows: the next section describes the intensification of agriculture in Uganda. Section 9.3 introduces the panel household data and soil fertility data used in this paper. We explain the estimation models and variables in Sect. 9.4 and discuss the estimation results in Sect. 9.5. The conclusion is in Sect. 9.6.

9.2 Intensification of Agriculture in Uganda

The need for replenishing soil fertility in Uganda is well recognized. Henao and Baanante (2006) estimate that the loss of nitrogen, phosphorus, and potassium (NPK) in the 2002–2004 cropping seasons was about 66 kg/ha/year, which puts Uganda at the 14th worst loser of soil nutrients among African countries. Land availability, at the same time, is rapidly declining in Uganda. Because of a high population growth rate and slow population movement from rural to urban areas, the arable land per person has declined by half, from 0.6 ha per person in the 1960s to 0.3 ha per person in the 2000s (FAO 2008). Although the current level of arable land per person in Uganda is comparable to that of southeast Asian countries, land productivity in Uganda is well below that of such countries, which enjoy high land productivity largely due to the Asian Green Revolution, high-yielding varieties (HYV), high fertilizer use, and irrigation. Ugandan farmers, therefore, have a strong need to intensify their agricultural production, but few of them have access to irrigated water or apply inorganic fertilizer because of high input to output price ratios, as we saw in Chap. 3. In addition, the selection of banana varieties has been carried out by local farmers in the past (Gabre-Madhin and Haggblade 2004).

Under these conditions, some successful Ugandan farmers have adopted a farming system that integrates dairy and crop production. In this farming system, farmers adopt improved dairy cattle that are crossbreeds of European and African cattle. Typically, the improved cattle are kept in stalls all day or at least at night. While the improved cattle are kept in the stalls, they drop manure and urine in the stalls. The manure and urine in the stalls can be easily collected and applied on banana and other crops. Note that the stall-feeding of cattle with internally cultivated feeds does not enhance the total amount of soil nutrients in the entire farming system (Buresh 1999). In fact, the total amount of nutrients will likely decline because of the export of nutrients from the plant–soil–animal system through harvested products and milk. Such a system, however, enhances the internal cycling of nutrients, and the efficiency depends on farm management at various steps starting from feeding animals (Rufino et al. 2006). For instance, because the fermentation process actually absorbs nitrogen from outside, putting unprocessed organic manure on cropping fields may reduce the nitrogen availability to crops. Thus, organic manure should be fermented for a few months before being applied as compost on crops. Many Ugandan farmers, however, apply organic manure on crops without fully fermenting it. According to our Uganda surveys, described in the next section, in more than 80% of the cases where organic manure is applied on crops, farmers apply it without fully developing it into compost. This suggests that there is a large potential for public intervention through extension services to properly instruct farmers how to prepare and apply organic manure.

In summary, the questions we ask in this chapter are as follows: (1) whether the adoption of dairy production is associated with an increase in the use of animal manure to fertilize bananas in the mixed system and (2) whether the use of animal manure is related to an increase in banana yields.

An evaluation of technology adoption, however, is not straightforward because the adopters could have had higher yields than non-adopters even before adopting the technology. Thus, in the following sections, we employ panel data of 894 households in rural Uganda and try to isolate the causal impacts of the adoption of improved dairy cattle on the organic manure application and banana yield.

9.3 Data and Descriptive Analyses

9.3.1 Data

The data used in this study come from 894 households in rural Uganda, surveyed both in 2003 and 2005 as part of the Research on Poverty, Environment, and Agricultural Technology (RePEAT) project, which was conducted by Makerere University, Foundation for Advanced Studies on International Development, and National Graduate Institute for Policy Studies (Yamano et al. 2004).¹ The survey was conducted in August–October of 2003 and 2005, and the sample for the RePEAT project largely builds upon and complements a completed research project on policies for improved land management in Uganda, conducted by the International Food Policy Institute (IFPRI) and Makerere University between 1999 and 2001 (Pender et al. 2001). Along with the 2003 survey, soil samples were also collected and later analyzed at the National Agricultural Research Organization (NARO) laboratory in Uganda.²

Table 9.1 shows the distributions of the 894 households divided into three regions.³ On average, the proportion of the sample households that own improved cattle increased from 10.1% to 12.6% over the survey periods. In the West region, the proportion increased from 10.8% to 16.6% over the same period. The West region is an important part of the milk shed in Uganda because of its favorable environment for dairy production and good access to Kampala, the capital city of Uganda. The recent liberalization of the milk market in Uganda seems to have encouraged milk production in this region. The proportion of households that own improved cattle remains at the same level over time in the Central region and has slightly increased in the East region.

¹The original sample size was 940. The second survey could not either find or interview 45 households, resulting in a 4.8% attrition rate. Because the attrition rate is small, we do not think that the attrition causes significant biases in our estimations.

²Other chapters in this book use soil fertility data that were analyzed at the World Agroforestry Center (ICRAF) by using the near-infrared reflectance spectroscopy (NIRS). In Uganda, however, soil samples were also analyzed at the NARO laboratory also. Because the NARO data were analyzed by usual chemical tests, not the NIRS, and were considered more accurate, we use the NARO data. The two data sets have a high correlation.

³The definitions of the three regions are provided at the bottom of Table 9.1.

Table 9.1 Cattle ownership, organic manure use, and banana yield in Uganda

Region ^a	Number of house-holds	% of banana growers	Improved cattle ownership		Organic fertilizer application on banana fields		Cooking banana yield	
			2003	2005	2003	2005	2003	2005
	(A)	(B)	(B)	(C)	(D)	(E)	(F)	(G)
	Number	%	%		kg/ha		ton/ha	
Eastern	394	75.9	7.9	10.2	98.7	103.3	3.9	4.0
Central	278	83.1	12.6	12.9	212.2	214.4	4.1	5.5
Western	223	49.3	10.8	16.6	184.4	552.6	11.5	11.0
Total	895	71.5	10.1	12.6	156.2	286.1	5.9	6.8

^aEastern region includes Burigi, Busia, Iganga, Jinja, Kapchorwa, Mayuge, Mbale, Pallisa, Sironko, Soroti, and Tororo districts. Central region includes Kayunga, Luwero, Masaka, Mpigi, Mukono, Nakasongola, Rakai, and Wakiso districts. Western region includes Bushenyi, Kabale, Kabalore, Kasese, Kisoro, Mbarara, Rukungiri districts

We also report the average organic manure application on banana plots in Table 9.1. The organic manure is usually produced by mixing cattle manure with crop residues. As we explained earlier, most farmers apply cattle manure mixed with crop residues and other organic matter (OM) without fully developing it into compost. In this paper, we do not distinguish the fully developed compost from dry animal manure because only a small proportion of farmers indicated that they applied compost. We also note that the measurement of the quantity of the organic manure application is difficult. We ask farmers about the quantity of the organic manure by the unit that they use most commonly, such as a wheelbarrow, and ask for the average dry weight of organic manure per unit of their choice. Because the organic manure is bulky and hardly ever weighed, such measurements are prone to errors. In addition, the quality and contents of organic manure also vary depending on feeds, materials mixed with the manure, and management. Thus, we need to treat the organic manure application with caution. Even with such caution, Table 9.1 suggests that organic manure application on banana plots has increased significantly from 156.2 to 286.1 kg/ha/year between the two surveys in Uganda. The organic manure application is much higher in the West region than in the other regions, where it has increased dramatically from 184.4 to 552.6 kg/ha. We speculate that this is associated with the increased adoption rate of improved cattle in the region.

Regarding banana yield, we find that in the West region it is about 11 ton/ha/year, which is much higher than the yields of 4–5 ton/ha in the other regions. The high banana yield is partly due to the high elevation and favorable rainfall in the West region. The yield figures are similar to ones found in Kalyebara et al. (2007), who find yields of 9 and 5 ton/ha/year for medium and low productivity subsistence farmers, respectively. Another study by Bagamba et al. (2007) also finds the average banana yield to be 6 ton/ha/year among smallholder banana farmers. Because estimating banana yields is difficult, finding comparable estimates in this and other studies suggests that our estimates are within a reasonable range.

9.3.2 Descriptive Analyses

More importantly, for the purposes of this chapter, we find that the organic manure application increased in the West region over the years where the improved cattle adoption increased significantly in Table 9.1. This suggests that the adoption of improved cattle has a positive impact on organic manure application, which may have contributed to the increased banana yield. To examine this hypothesis further, in Table 9.2, we stratify our households into three groups according to cattle ownership: no cattle, local cattle only, and some improved cattle. In Table 9.2, we find that the average organic manure application is higher among households with improved cattle than the other households. It is over 500 kg/ha among households with improved cattle but is only 208 and 132 kg/ha among households with only local cattle and no cattle, respectively. The average banana yield is 7.3 ton/ha among households with improved cattle, which is higher than the other households. The high average yield is a result of larger sizes of bunches and greater numbers of bunches produced among the households with some improved cattle. The average size of banana bunches is 14 kg among the households with improved cattle but is about 11 to 12 kg among the other households. The number of bunches produced

Table 9.2 Banana production by cattle ownership

	All banana plots Mean (s.d.)	By cattle ownership		
		No cattle Mean (s.d.)	Local cattle only Mean (s.d.)	Improved cattle Mean (s.d.)
Organic manure use in kg s/ha/year	223 (724.8)	132 (207.9)	208 (696.3)	501 (1,078)
Banana yield in ton/ha/year	6.4 (8.1)	6.4 (8.2)	5.9 (7.6)	7.3 (8.6)
Size of banana bunch in kg s/bunch	11.9 (6.7)	11.0 (6.4)	12.0 (6.4)	14.2 (7.8)
Number of bunches in number/ha/year	141 (180.6)	136 (178.5)	128 (169.3)	182 (202.0)
Size of banana plot in ha	0.91 (0.98)	0.81 (0.94)	0.94 (1.1)	1.10 (0.9)
Banana value production in USD/ha	438 (545.1)	413 (506.3)	439 (561.1)	504 (606.9)
Family labor cost	n.a.	n.a.	n.a.	n.a.
Hired labor cost in USD/ha	21.6 (74.1)	16.1 (61.4)	21.4 (73.6)	37.0 (100.4)
Inorganic fertilizer cost in USD/ha	1.2 (22.5)	1.5 (28.8)	0.8 (12.7)	1.4 (18.5)
Banana income in USD/ha	415 (542.1)	396 (506.5)	417 (559.4)	466 (596.3)
Number of banana plots	1,566	741	553	272

Numbers in parentheses are standard deviations

is about 182 bunches per ha among the households with improved cattle, while it is about 130 bunches per ha among the other households.

Regarding the costs, applying organic manure on banana plots requires a significant amount of labor. Thus, it may not be profitable to use it on banana plots. Unfortunately, we do not have information about family labor use on banana production. Instead, we only have paid-out costs, such as hired labor and purchased fertilizer costs. Although we find that hired labor cost is higher among the households with improved cattle than the other households, it costs only \$37 per ha, while the revenue is about \$500. Thus, the income, which is the revenue minus the paid-out costs, is \$466 per ha among households with improved cattle. Although it is not clear if the economic profit, which is the income minus the cost of the family labor, of the households with improved cattle is still higher than that of the other households, the income of the households with improved cattle is higher.

To identify the causal impact of the adoption of improved cattle on the organic manure application, we take advantage of having panel data and stratify the samples into four groups based on the adoption of the improved cattle over time (Table 9.3). The first is the group of households that did not own improved cattle in both 2003 and 2005 (we call this group No-No). The second is the group of households that owned improved cattle in 2003 but not in 2005 (Yes-No). The third is the group of households that did not own improved cattle in 2003 but own at least one in 2005 (No-Yes). The last group is the group of households that owned improved cattle both in 2003 and 2005 (Yes-Yes). Note that improved cattle are not the only animals from which farmers collect manure. They collect manure from local cattle and other smaller animals as well. In Table 9.3, for instance, we find that farmers who do not own improved cattle use some organic manure. We hypothesize that improved cattle are the largest contributors and test this hypothesis in Table 9.3 and later econometric analyses.

The No-Yes group provides us a before–after comparison of the adoption of improved cattle over time. The organic manure application of the No-Yes group increased from 158.8 to 732.6 kg/ha, an increase of 573.8 kg/ha. Admittedly, there are only about 70 banana plots that belong to this group, and measurements of the organic manure applications in general have large measurement errors. As a result, the standard errors are relatively large. The difference over the 2 year period of this group, nonetheless, is statistically significant at the one percentage level. We also

Table 9.3 Organic manure application on banana by improved cattle ownership

Ownership of improved cattle in 2003 and 2005	Number of banana plots		Organic manure application per ha		
	2003	2005	2003 kg s/ha	2005	Dif.
No-No	581	612	132.7	184.8	52.0
Yes-No	38	37	174.2	340.0	165.7
No-Yes	64	78	158.8	732.6	573.8**
Yes-Yes	79	77	318.4	613.4	295.1*
	762	804	156.2	286.1	129.9**

* Significant at 5%, ** significant at 1%

find a large increase of 295 kg/ha in the organic manure application over time among the Yes-Yes group. Thus, it seems that among improved cattle owners, the use of organic manure has increased over time. On the other hand, the amount of organic manure has only increased slightly among the No-No group. The results in the table, at least, suggest that there may be a causal impact from the improved cattle ownership to the organic manure application.

9.3.3 Soil Sampling and Fertility

Along with the 2003 survey, we also conducted soil sampling and tested for soil contents. Note, however, that we did not collect soil samples from banana fields because the main purpose of the soil sampling was to analyze soils across a common cereal crop in the region (maize) and the budget was insufficient to collect and test soil samples from all plots. Thus, we collected soil samples from one annual cereal crop plot cultivated by a sampled household in the first cropping season of 2003. When a household did not produce a cereal crop, we did not collect soil samples. The total number of soil samples is 632 from 632 households. Out of them, only 565 soil samples provide valid soil analysis results. The results are presented in Table 9.4. The soil samples were collected at a depth of 0–20 cm depth at five different locations within each plot and mixed. The soil samples were air-dried and ground to pass a 2 mm sieve and analyzed for pH, OM and texture at the National Agricultural Research Organization (NARO) Laboratory in Uganda. Soil pH was measured using a soil to water ratio of 1:2.5.

In Table 9.4, we find that soil organic matter (SOM) in the West region is 6.7%, which is much higher than the 4.7% in the Central region and the 4.2% in the East region. SOM is derived from the decayed tissues of plants and animals and from animal excreta, particularly urine (Ngugi et al. 1990). The decayed organic remains contain carbon and nitrogen, in addition to other elements, vital for plant growth. Physically, SOM provides absorptive areas for water and nutrients. Because it is now recognized that SOM tightly controls many soil properties and major biogeochemical cycles, its status is often taken as a strong indicator of soil fertility and

Table 9.4 Soil sampling and fertility

	Number of house-holds (A)	% of house-holds with soil samples (B)	Organic matter (C)	pH		Texture	
				Mean	Too low (pH < 6)	Sand	Clay
				(D)	(E)	(F)	(G)
Region ^a	Number	%	%	Mean	%	%	%
Eastern	394	77.4	4.2	6.4	6.6	56.4	31.5
Central	278	50.4	4.7	6.3	9.9	57.2	31.4
Western	223	53.8	6.7	5.9	23.7	59.2	24.0
Total	895	63.1	4.9	6.3	11.9	57.2	29.9

^aSee the note at the bottom of Table 9.1 for the definitions of the regions

land degradation (Manley et al. 2007). Thus, the data in Table 9.4 suggest that the soil fertility in the West region is much better than that of the other regions.

Soil pH strongly influences the availability of various soil nutrients to plants. Too low pH (acid) or too high pH (alkaline) may impair plant growth (Ngugi et al. 1990). On average, we find that the soils are more acidic in the West region than in the East and Central regions. However, what matters is if it is too acid or alkaline. Thus, in the later analyses in this paper, we create a dummy variable for soils with too low pH (<6). We did not find soils that are too high in pH (>8). Regarding the soil texture, we find it is slightly more sandy in the West region than in the other two regions. In the following analyses in this paper, we use the following soil variables: the SOM, one dummy for high acidity (i.e., too low pH), and the proportion of sand. Because these variables are stable in the short run, we treat them as exogenous variables.

9.4 Estimation Models and Variables

9.4.1 Estimation Models

First, let us consider the determinants of the adoption of improved cattle. Improved cattle are more expensive than local cattle. For instance, an improved cow costs about \$200 per head, while a local cow costs about \$80 per head. An improved heifer is also much more expensive than a local heifer. Thus, wealthier households are more likely to adopt improved cattle. The need to adopt improved cattle is high in areas where there is little grazing land. Historically, cattle are grazed on communal grazing lands in Uganda. Although there remain some areas where cattle are still grazed, the communal grazing land has been diminishing rapidly because of the declining availability of farm land (Otsuka and Place 2001). In our 2003 survey, we have inquired about the availability of communal grazing land per household at the community level.⁴ Out of the 94 communities, 50 communities replied that there is no communal grazing land. Even among the 44 communities where there is some communal grazing land, the median size of the communal land is about 0.2 ha per household. Farmers are induced to adopt stall-feeding for which improved cattle are better suited as they produce more milk than local cattle if cattle are well fed. Thus, we expect that the adoption of improved cattle and the size of communal land have a negative relationship. By the same argument, we also expect

⁴We define communal land as any land that local people have common access to. Among the 94 communities in our samples, there are 82 patches of communal land. Out of them, 62 patches are communal grazing or pasture land, 14 are private land but open to the public, and the rest are bush and natural forests. Among the 62 patches of communal grazing land or pasture land, only 5 patches have any use restrictions, while 6 patches of the 14 privately owned land have restrictions.

that population pressure has a positive relationship with the adoption of improved cattle. To test these hypotheses and estimate the determinants of the number of improved cattle owned at the household level, we estimate the following model:

$$N_{hct} = X_{hct}\beta_X + e_{hct} \quad (\text{Tobit}), \quad (9.1)$$

where N_{hct} is the number of improved cattle owned by household h in community c at time t ; X_{hct} is a set of household and community characteristics; and e_{hct} is the error term. The household characteristics include variables that represent household wealth and labor availability, and the community characteristics include the availability of communal grazing land. We describe all the variables in the next subsection in detail. For comparison, we also estimate the same model for local cattle. Because local cattle are mainly grazed, we expect that the availability of grazing land and population pressure have the opposite effects on the local cattle than on the improved cattle.

Next, we estimate the impacts of the number of improved cattle per ha on the application of organic manure on banana plots. We estimate the amount of organic manure used at the plot level. A household may have multiple banana plots, which have different plot characteristics. We expect, for instance, that a plot that is farther away from the homestead receives less organic manure than one near the homestead because organic manure is bulky and heavy. Thus, we control for observed plot characteristics, such as the distance from the homestead to the plot and the size of the plot. Banana farmers may apply more organic manure on plots with poor soil fertility. If we fail to control for the effect of the soil fertility, the estimated impact of organic manure on the banana yield would be biased downward. Fortunately for this study, we have soil fertility data on more than 60% of the sample households. Because the soil samples are taken from cereal crop plots, we match them at the household level to the banana production. Thus, the soil fertility variables are at the household level. The estimation model is

$$Y_{phct} = \beta_N N_{hct} + S_{hct}\beta_S + P_{phct}\beta_P + X_{hct}\beta_X + u_{phc} + e_{phct} \quad (\text{Tobit}), \quad (9.2)$$

where Y_{phct} is the amount of organic manure applied on plot p of household h in community c at time t ; S_{hct} is a set of soil characteristics of household h in community c at time t ; P_{phct} is a set of plot characteristics; and u_{phc} is the unobserved fixed plot effects. The rest of the variables are as defined before.

Our main concern is the correlation between the independent variables and the omitted variables. Of particular concern, the number of improved cattle and amount of organic manure could both be correlated with unobserved plot characteristics, u_{phc} . Such biases could be eliminated, at least, partly by using the instrumental variables model. The lack of plausible identification variables, however, makes it difficult to use the instrumental variables model. As long as panel data are available, one can apply the fixed effects model. A major problem of applying the least-square, fixed-effects (FE) model is that the amount of organic manure application per ha is censored at zero and the least-square, FE model would be biased by the censoring.

Thus, in this chapter, we simply report the Tobit estimates. To examine if the Tobit estimates are biased, we estimate the same model with the random and FE models at the household level, ignoring the censoring, to see if the estimated coefficients differ between the two models. If the results are substantially different between the two models, then the existence of omitted variables that create biases is suspected. By examining the direction of the biases, we can determine at least if the Tobit estimates are under- or over-estimated.

Finally, we estimate the banana yield model as follows:

$$Z_{phct} = \beta_Y Y_{phct} + S_{hct} \beta_S + P_{phct} \beta_P + X_{hct} \beta_X + e_{phct}, \quad (9.3)$$

where Z_{phct} is the banana yield in terms of tons per ha, and the rest of the variables are as defined before. In this model, we are also concerned about the potential correlation between the omitted variables and the independent variables, especially the amount of organic manure applied. By following the same argument as for the previous model on the organic manure application, we estimate Eq. 8.3 with the OLS and FE models to see if the OLS estimates are biased.

9.4.2 Variables

The first dependent variable is the number of improved cattle owned by the household, which includes all types of cattle, such as calves, heifers, cows, and bulls. We simply count the number of cattle and do not distinguish types. Although this may overestimate the presence of calves and heifers because they produce less manure than cows and bulls, we simply count calves and heifers equally as cows and bulls because we do not have accurate information on the age or weight of each animal.⁵ In addition, we also use the number of local cattle owned as another dependent variable to compare the results with the ones on improved cattle.

The second dependent variable is the amount of organic manure, in tons per ha per year, applied on the banana plot. Although we have asked separately for animal manure in dry form, wet form, and compost in the surveys, we find that most farmers simply applied animal manure in dry form without developing it into compost. Thus, we simply combine them. Note, however, that it is quite difficult to know how farmers prepare organic manure before application. The quality of the organic fertility could differ widely from one farmer to another. Such measurement errors

⁵ This makes the impact of the number of cattle on the organic fertilizer application underestimated as compared to only counting the number of cows and bulls. In this chapter, we should consider the impact of the number of cattle as the impact of any cattle. We may employ a scaling unit to convert the number of any cattle into the number of cows or bulls.

in the quality of the manure will generate an attenuation bias, which biases the estimated coefficient toward zero, when simply the amount of the manure is used as an independent variable. Thus, if we find a positive coefficient, we should note that it is a conservative estimate, and the unbiased estimator could be larger in magnitude than the estimated coefficient.

The third dependent variable is the banana yield, in tons per ha per year. This is also a difficult variable to measure. To estimate the banana production, we have asked respondents the number of bunches of banana harvested over the past year and the average weight of the typical banana bunch. By multiplying the number of bunches with the average weight, we obtain the total quantity of banana harvested over the past year and estimate the banana yield by dividing it with the banana plot size in ha. In this paper, we only focus on cooking banana and exclude brewing and dessert banana because cooking banana is the dominant variety, which occupies more than 90% of all the banana plots.

The independent variables include three sets of variables: plot, household, and community characteristics. The plot characteristics include the log of plot size (in ha), the walking time from the homestead to the plot, and a dummy variable for rented-in plots. The second set of independent variables is the household characteristics, which include the number of men (age 15 and older), the number of women (age 15 and older), the number of boys (age 14 and younger), and the number of girls (age 14 and younger) in the household. These variables are expected to measure the labor availability in the household. The household characteristics also include the maximum education levels of male and female adult household members, a dummy variable for female-headed households, the owned land size in ha, and the value of assets, which include farm equipment and furniture.

The community characteristics include some important variables. As previously mentioned, out of the 94 communities, 50 communities have no communal grazing land. Among the 44 communities that have some communal grazing land, the median size of the communal grazing land per household is 0.2 ha per household. Thus, it is clear that, even in communities with communal grazing land, the availability of the grazing land is very limited. A related variable is the population density measured at the district level. This variable measures the availability of labor and the demand for consumption goods, such as milk. We use the monthly rainfall information from 11 rainfall stations in Uganda and match them with our household data at the district level. For each district, we chose one rainfall station, which is closely located to the district and belongs to the same agroecological zone. From each rainfall station, we have monthly rainfall data for 7 years, starting from 1999 to 2005. Then, we calculated the average annual rainfall over the 7 years. Because the 2003 survey asked about the second cropping season in 2002 and the first cropping season in 2003, we aggregated the monthly rainfall from July 2002 to June 2003. For the 2005 surveys, we have also aggregated the monthly rainfall from July 2004 to June 2005. In addition, we created a rainfall shock variable by subtracting the 7 year average annual rainfall from the corresponding annual rainfall in the survey years.

9.5 Results

9.5.1 *Adoption of Improved and Local Cattle*

The results in Table 9.5 indicate that the availability of communal grazing land has a strong negative impact on the number of improved cattle, while it does not have any impacts on the number of local cattle. The estimated coefficient suggests that the average number of improved cattle increases from 0.1 to 0.3 if the size of the communal grazing land declines from 0.5 ha per household to zero.⁶ This is consistent with our expectation that improved cattle are adopted more in areas with no or little grazing land. Because improved cattle are more than twice as expensive as local cattle, it is expected that the asset value has a larger positive impact on the number of improved cattle owned than on the number of local cattle. Contrary to the expectation, however, we find a larger coefficient on the local cattle than on the improved cattle. The estimated coefficients suggest that the number of improved cattle increases from 0.16 to 0.29 when the asset value changes from the 25th to the 75th percentile, while the number of local cattle increases from 1.1 to 1.8 for the same change in asset value.

Regarding other household characteristics, we find that the number of boys in the household increases the number of local cattle owned. This is probably because boys usually graze local cattle. In contrast, we find that the number of adult males increases the number of improved cattle. This is because it is the men who spend considerable amount of time to take care of the expensive improved cattle that are stall-fed. The number of women and girls does not have any influence on the number of improved and local cattle owned. Thus, it seems that men provide important family labor for improved cattle, while boys provide labor for local cattle in Uganda.

9.5.2 *Determinants of Organic Manure Application*

The results in Table 9.6 indicate that one additional improved cattle per ha increases the organic manure application on banana plots by 232 kg/ha when the soil fertility data are not included (column A). After including the soil fertility variables, the size of the coefficient shrinks slightly to 218 kg/ha. In contrast, we find that one additional local cattle increases the organic manure application only by about 52 kg/ha. This is much smaller than the impact of the improved cattle on the organic manure application. Because local cattle are mainly grazed in open fields, it is difficult to collect manure from them.

⁶We conduct a simple simulation by predicting the censored dependent variables when we change the value of the independent variable from one value to another.

Table 9.5 Determinants of improved and local cattle holdings per ha at the household level (pooled-tobit model)

	Improved cattle (A)	Local cattle (B)
Community characteristics		
Grazing land	-4.651*** (-4.90)	-0.595 (-0.97)
Grazing land squared	0.550*** (4.68)	0.0671 (0.84)
Population density	-0.00779*** (-3.07)	-0.00504 (-1.60)
ln(altitude)	-3.820* (-1.84)	1.820 (0.74)
Annual rainfall (100 mm)	0.00413*** (4.65)	0.00291*** (2.66)
Household characteristics		
Max. education of men	0.0112 (1.47)	0.0234*** (3.07)
Max. education of women	0.00421 (0.70)	0.00804 (1.37)
Number of men	0.489*** (3.65)	0.239* (1.69)
Number of women	-0.0582 (-0.41)	0.105 (0.69)
Number of boys	0.00620 (0.053)	0.279** (2.39)
Number of girls	0.000304 (0.0026)	0.0767 (0.64)
ln (asset value)	0.873*** (4.91)	1.319*** (7.46)
Female head (=1)	-0.951 (-1.44)	0.659 (1.11)
Land size	0.108 (1.61)	-0.0638 (-1.41)
Land size squared	-0.000960 (-1.43)	0.000195 (0.82)
Year 2005	0.307 (0.77)	-0.521 (-1.26)
Constant	8.277 (0.56)	-34.80** (-1.98)
Number of households × 2 years	1,727	1,727

Numbers in parentheses are z-values.

* Significant at 10%, ** significant at 5%, *** significant at 1%

The estimated coefficients in Table 9.6 could be biased because of unobserved household characteristics. Thus, we have separately estimated the random and FE models at the household level. Although the estimates from the random and FE models do not control for censoring, the results indicate that the random-effects

Table 9.6 Determinants of organic manure application on banana plots.
Dependent variable: the organic manure application per ha of banana plots

	Basic model (A)	With soil data (B)
No. of improved cattle per ha	232.2*** (4.00)	218.1*** (3.77)
No. of local cattle per ha	51.26** (1.97)	52.29** (2.00)
Soil fertility in 2003		
Organic matter (%)		-166.6*** (-2.65)
Too acid (pH<6)		-71.12 (-0.24)
Sand (%)		5.375 (0.57)
No soil data dummy		-719.6 (-0.97)
Plot characteristics		
ln (plot size)	215.0* (1.94)	212.3* (1.91)
Walking distance (min)	-33.98*** (-3.93)	-33.15*** (-3.80)
Rent-in land dummy	-143.6 (-0.41)	-109.7 (-0.31)
Household characteristics		
Max. education of men	-0.237 (-0.059)	0.235 (0.059)
Max. education of women	-0.757 (-0.26)	-0.624 (-0.22)
Number of men	-61.40 (-0.83)	-52.78 (-0.72)
Number of women	8.725 (0.11)	6.146 (0.080)
ln(assets)	401.8*** (4.47)	377.1*** (4.22)
Community characteristics		
ln(altitude)	2,288*** (3.34)	2,953*** (3.82)
Population density	0.325 (0.40)	-0.368 (-0.42)
Rainfall shock	-1,922*** (-2.85)	-1,787*** (-2.65)
Average annual rainfall	-0.541** (-2.30)	-0.473* (-1.87)
Year 2005 dummy	854.1*** (3.75)	851.7*** (3.74)
Constant	-23,227*** (-4.50)	-27,080*** (-4.69)
Number of plots	1,559	1,559

Numbers in parentheses are z-values

* Significant at 10%, ** significant at 5%, *** significant at 1%

coefficient on the number improved cattle is biased downward: it is 57.3, with a z -value of 4.62, in the random-effects model, and 77.5, with a z -value of 3.74, in the FE model. Thus, these results suggest that the estimated coefficients of the number of improved cattle reported in Table 9.6 could be biased downward and thus are conservative estimates. Thus, the real impact is likely to be larger than 218 kg/ha.

Regarding the soil fertility, we find that the SOM has a negative coefficient, indicating that banana farmers are applying more organic manure on poorer soils than more fertile soils. A one percentage point increase in the SOM reduces the organic manure application by more than 167 kg/ha. Banana farmers may have recognized the declining soil fertility and wanted to supplement the poor soils with organic manure. This is consistent with Hypothesis 3 on the impact of soil fertility on the use of organic manure. As we expected, the walking distance from the homestead to the plot has a strong negative impact on the organic manure application. The estimated coefficient indicates that the amount of organic manure applied decreases by more than 300 kg/ha if the plot is 10 min away from the homestead. This is understandable because of the bulkiness and heaviness of organic manure.

9.5.3 *Banana Yield Model*

Finally, we present the results on banana yield in Table 9.7. The results of the FE model indicate that the organic manure application has a strong impact on banana yield. The banana yield increases by about 16.7% when unobserved household fixed characteristics are not controlled for in Column A. When they are controlled for in Column B, the impact becomes smaller, 10%. The direction of the bias is consistent with the assumption that the unobserved household characteristics, such as farmer ability, are positively correlated with both the organic manure application and banana yield. Note that because the amount of organic manure has a large measurement error, the estimated coefficient could be downward biased as we discussed earlier. Thus, we should treat the estimate as a conservative estimate. Furthermore, the estimated coefficient of the organic fertility only captures the short-run impact on the banana yield. In the long run, organic manure improves the SOM, which also has a strong impact on the banana yield. According to the results in column A of Table 9.7, a one percentage point increase in the SOM increases the banana yield by 7%. Even though we need to be careful about interpreting the results because the SOM information was taken from the cereal plot of the same household, the result indicates a strong relationship between the banana yield and the SOM. Because organic manure increases the SOM in the long run, the long-run impact of the organic manure is partly captured in the SOM variable.

Table 9.7 Determinants of banana yield

	ln (yield, ton/ha)	
	OLS	HH FE
	(A)	(B)
Organic fertilizer (tons/ha)	0.167*** (4.06)	0.101** (2.04)
Soil fertility in 2003		
Organic matter (%)	0.0728*** (4.26)	
Too acid (pH < 6)	0.0799 (0.85)	
Sand (%)	0.00437 (1.53)	
No soil data dummy	0.837*** (3.86)	
Plot characteristics		
ln (plot size)	−0.289*** (−8.64)	
Walking distance (min)	0.00163 (1.10)	
Rent-in land dummy	−0.249** (−2.21)	
Household characteristics		
Max. education of men	−0.00112 (−0.84)	
Max. education of women	−0.000585 (−0.61)	
Number of men	−0.0382* (−1.66)	−0.0185 (−0.39)
Number of women	0.00581 (0.25)	−0.000813 (−0.020)
ln(assets)	0.226*** (8.23)	0.145** (2.46)
Community characteristics		
ln(altitude)	1.665*** (7.27)	
Population density	−0.000468* (−1.90)	
Rainfall shock	−1.307*** (−6.49)	−0.117 (−0.53)
Average annual rainfall	−0.000145** (−2.10)	
Year 2005 dummy	0.0613 (0.87)	
Constant	−14.34*** (−8.42)	−0.554 (−0.78)
Number of households	630	630
Number of observations	1,537	1,537

Numbers in parentheses are z-values

* Significant at 10%, ** significant at 5%, *** significant at 1%

9.6 Conclusion

In this chapter, we have estimated the impact of a mixed farming system of intensive dairy and banana production in Uganda by using panel data in 2003 and 2005. The mixed farming system is based on the use of manure generated from improved dairy cattle and is a desirable farming system in Uganda where inorganic fertilizer is expensive and hardly used. We find that improved cattle are adopted more in communities where there is no or only limited communal grazing land. It seems that Ugandan farmers are shifting from grazing to zero- or semi-zero grazing and from local to improved cattle because of the increasing land scarcity. The regression results indicate that an increase of one improved cattle per ha increases organic manure application by at least about 218 kg/ha. The additional application of organic manure by 1 ton/ha increases banana yield by about 10%. Note that this is only the short-term impact of organic manure on the banana yield. In the longer run, the organic manure improves the SOM, which is also found to have a strong impact on the banana yield. A one percentage point increase in the SOM increases the banana yield by 7%.

In addition to the direct impact of the organic manure on the banana yield, there are other reasons to promote the intensive dairy and banana cropping system. First, the estimated coefficients in this study are conservative estimates and the real and long-term impacts could be much larger. Second, the intensive dairy and banana farming system increases the organic manure application in a country where most farmers do not apply any inorganic fertilizer. The organic manure improves the physical soil structure and provides nutrients to soils, which have been depleted over a long time. Third, the intensive dairy and banana farming system helps farmers to diversify their income and become less vulnerable to natural and economic shocks. Fourth, and finally, the system has large room for improvement. According to our surveys, in more than 80% of the cases, farmers apply manure without fully developing it into compost. The benefits of organic manure and how to handle it are still not known by farmers in Uganda. This suggests that there is a large potential for public intervention through extension services. Although banana is a major crop in Uganda and other central African countries, the number of studies is relatively small compared to other major crops such as maize. Thus, there is a need to further investigate how to intensify banana production in combination with organic manure application.

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Chapter 10

Technology, Soil Fertility, and Poverty: The Case of NERICA Rice in Uganda

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Abstract This chapter examines the effect of new farm technology on the income of poor farmers in Sub-Saharan Africa (SSA) using the case study of NERICA rice in Central and Western Uganda. NERICA has the potential to increase per capita income by \$20 (12% of actual per capita income) and to decrease the poverty incidence, measured by the head count ratio, by 5% points. Such a positive effect of NERICA, however, can only be realized when its adoption is combined with the use of appropriate cropping patterns to maintain soil fertility. The study also finds that accessibility to information and experience of non-NERICA rice cultivation increase the probability of adopting NERICA.

Keywords Technology adoption • NERICA • Poverty • Uganda • Cropping pattern

10.1 Introduction

While poverty has been a critical issue in the development of economics for many years, its importance was highlighted by the declaration of the Millennium Development Goals (MDGs) in the United Nations (UN) resolutions and agreements

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in 2000. Some studies such as Sahn and Stifel (2003) predict that the MDG targets are almost impossible to achieve, especially in SSA. To pursue the MDGs, the world must accelerate capacity building, the improvement of economic policies, and the delivery of appropriate investments (Sachs 2005). Since most of the poor live in rural areas and, hence, the livelihoods of rural households depend on agriculture, developing and disseminating improved agricultural technologies must be a central strategy, one which requires urgent attention (NEPAD 2004; Deininger and Odiki 2001).

In areas where land is scarce, including high-potential areas in SSA, agricultural production should be enhanced by developing and disseminating fertilizer-responsive and high-yielding technologies, which are also land-saving (Hayami and Ruttan 1985). Some studies show, however, that with the currently available technologies and inefficient marketing systems characterized by high fertilizer prices and low crop prices in SSA, it is unprofitable for farmers to increase the use of chemical fertilizer (Pender et al. 2004; Otsuka and Kalirajan 2005, 2006; Chaps. 3 and 4). Unless improvements are made in the market systems as well as in the development of more profitable technologies, neither input application nor agricultural output will be increased substantially, perpetuating a vicious cycle of unfavorable relative prices and low productivity.

New Rice for Africa (NERICA) is a set of high-yielding upland rice varieties suited to the African environment obtained by crossing rice varieties of Asian origin from the species *Oriza sativa* with varieties of African origin from the species *O. glaberrima*. The resulting traits have been considered by many to offer significant opportunities for productivity increases and poverty reduction in Africa (Jones et al. 1997). However, studies of the impacts of NERICA in smallholder agriculture have been limited. A small number of studies have examined the uptake of different NERICA varieties in West Africa (Diagne 2006a, b; Diagne et al. 2007; Agboh-Noameshie et al. 2007). There has, however, been limited publication of studies investigating the ways that NERICA may offer particular opportunities for promoting pro-poor growth. This chapter presents information from farm surveys on NERICA's pro-poor characteristics specifically in Uganda where the adoption of NERICA has been rapidly increasing since 2004 and which has become the third largest NERICA producer in Africa following Guinea and Cote d'Ivoire (Africa Rice Center (WARDA) FAO/SAA 2008).

Recently, the Ugandan government has introduced NERICA as one of its poverty eradication strategies, as described in Kijima et al. (2008). NERICA is particularly useful because rice can serve both as a cash crop and a subsistence food crop, and it is cultivable in most parts of Uganda, thanks to NERICA's shortened maturity and drought tolerance. Moreover, the yield of NERICA is much higher than that of traditional upland rice (Kijima et al. 2006).

NERICA's desirable traits are expected to boost rice production and income for rural Ugandan households. A critical question at present concerns the extent to which NERICA has contributed to improved agricultural income, poverty reduction, and income distribution in rural Uganda. In order to answer these questions, it is critically important to identify the determinants of NERICA adoption, as new

technology may particularly favor educated, wealthy farmers. This chapter, thus, examines the effect of NERICA on poverty reduction and income distribution by using household survey data collected in 2005 in ten NERICA growing areas in rural parts of Uganda.

It is important to emphasize here that in most of the sample areas, NERICA is the first upland rice variety ever introduced. The total cultivated area has been increased by converting fallowed land into NERICA fields to avoid reducing the size of land planted to traditional subsistence crops such as beans, maize, and cooking banana. In a few sample areas, however, NERICA has replaced traditional crops such as maize and millet.

The rest of the chapter is organized as follows. [Section 10.2](#) provides an overview of NERICA adoption in Uganda and presents the household data used in this study. In [Sect. 10.3](#), we explain the analytical framework on NERICA adoption and show those estimation results. [Section 10.4](#) provides the specification of the crop income function and the regression results. [Section 10.5](#) shows the measurement of the effect of NERICA on household income distribution and poverty. [Section 10.6](#) discusses the policy implications and conclusions.

10.2 Data

At the time of the data collection, the number of farm households growing NERICA was increasing in areas with NERICA seed dissemination programs. The number of such areas in the nation as a whole, however, was limited. In areas without such programs, there were very few rice growing households. Therefore, we use two data sets to conduct the analyses in this chapter. One is a relatively large and representative household survey covering broad areas of rural Uganda except the Northern districts, and the other is a comparatively smaller survey, which contains more detailed questions regarding NERICA. We call the former the “RePEAT survey” and the latter the “NERICA survey.” The RePEAT survey data are mainly used to assess how the NERICA sample is different from the representative sample. Unless we indicate the “RePEAT survey” as the data source, the analyses in the later sections are based on the NERICA survey data.

To obtain a relatively large sample of farmers who have adopted NERICA, we intentionally chose ten sample communities from NERICA growing areas. At the same time, we attempted to achieve broader geographical coverage and to choose areas with different NERICA-growing experiences.¹ In each sample community, we drew a random sample of 25 households that grew NERICA (“NERICA households,” hereafter) and 15 households that did not grow NERICA in the second

¹ The selected areas are the districts of Masindi, Kibaale, Kamwenge, Hoima, Mbarara, Wakiso, Mpigi, Mubende, Kiboga, and Luwero. In half of the areas, NERICA was newly introduced in 2004. Each area covers about three LC1s.

cropping season of 2004 (“non-NERICA households,” hereafter). The total number of sample households is, therefore, 400.²

The NERICA survey questionnaire contains detailed questions about the adoption history of NERICA, the labor and capital inputs used for NERICA production, and the past cropping patterns of the current NERICA plots. The structure and questions in the other sections of the NERICA survey questionnaire basically follow those of the RePEAT survey, allowing us to make comparisons between these two surveys. Since many questions are related to NERICA production, we use a different questionnaire for the non-NERICA households in which questions about knowledge of NERICA are asked.

According to the RePEAT data collected in 2005, the adoption rate of rice, including lowland rice, is 6.3%, out of which 0.67% grew NERICA (Kijima and Sserunkuuma 2011, forthcoming). In the NERICA growing areas, the adoption rate of NERICA is 16.5%.³ The reason why the adoption rates are so different between the two samples may be due to the non-exposure bias. The majority of households have not yet adopted NERICA simply because NERICA was just introduced and the scale of the dissemination program was not large enough to provide NERICA seeds to all the households that are potentially interested in growing rice. As explained in Diagne (2009), just after NERICA was introduced to Uganda, the non-exposure bias tended to be serious. Even in West African countries where NERICA was introduced much earlier than in Uganda, the adoption rate without correcting the non-exposure bias is low: 4% in Cote d’Ivoire (2000), 20% in Guinea (2001), 19% in Benin (2004), and 40% in Gambia (2006). However, once the non-exposure bias issues are corrected, the adoption rates are found to increase to 22%, 61%, 45%, and 85%, respectively (Diagne 2009).

Table 10.1 shows the per capita income and the share of income sources by the per capita income quartile.⁴ The last column indicates whether the means of the variables for lower- and higher income households are statistically different. Note that the income distributions of the NERICA survey and the RePEAT survey households in the same districts can be considered equal from the Kolmogorov-Smirnov test. Thus, the income quartiles in the NERICA survey are comparable to those in the smallholder population in Central and Western Uganda.

There are several important findings in this table. First, the total land area per person increases from the lowest to the highest income quartile (see the last row),

²To control for over-sampling of the NERICA households, we calculated the sampling weights from the information collected during the NERICA survey. These weights are used to compute the descriptive statistics and to conduct the regression analyses, where the sampling weight for the NERICA households in area i is calculated by the ratio of the total number of NERICA growing households in area i over the number of sampled NERICA households in that area, and a similar scheme is applied for non-NERICA households.

³The adoption rate in the sample area is calculated by dividing the number of NERICA adopters by the total number of households in the sample area. We obtained the names of all the NERICA adopted households in our sample areas to draw a stratified random sampling.

⁴How income was calculated is explained in Kijima et al. (2008).

Table 10.1 Per capita income, income sources, NERICA adoption, and land endowment by income quartile^a

	Quartile of income per capita				
	1	2	3	4	
Total land area per household member (ha)	0.35	0.52	0.69	0.76	**
Percent of area planted to NERICA in total land area	16.7	23.0	12.3	17.6	**
Per capita income (\$)	41	102	168	361	**
Share (%) of crop income	78	79	65	63	**
Share (%) of livestock income	12	7	11	8	
Share (%) of other income	10	14	24	30	**
Share (%) of rice income	28	34	21	22	**

** indicates that the means of the higher income (quartiles 3 and 4) and lower income (quartiles 1 and 2) households are statistically different at significance levels 1%

^a All the means and proportions are calculated with sampling weights

indicating the importance of land as a source of income, which is typical in traditional agriculture (Estudillo and Otsuka 1999). Thus, land-poor households in the rural areas of Uganda tend to be poorer.⁵ Second, whereas the area planted to NERICA is largest in the higher income quartiles 4, the proportion of NERICA planted area in total land is highest in the lower income quartiles. This may suggest that, comparatively, poorer households are not disadvantaged in adopting NERICA, which is similar to the Green Revolution experience in Asia (David and Otsuka 1994). Third, the major income source for the sample households is crop cultivation, which accounts for 70% of the total income on average. For households in the lower income quartiles, the crop income shares are higher than those for households in the higher income quartiles. Specifically, the rice income share is highest in the second lowest quartile (34% of income), and the rice income share of the bottom quartile (28%) is much higher than that of households in higher income brackets. These findings suggest that introducing NERICA might have a pro-poor effect on income distribution. These results from the descriptive analyses will be tested econometrically in the later sections.

Table 10.2 shows the yield per ha of NERICA in 2004, separately with and without rice-growing experience. Out of 254 NERICA households, 127 households had no previous rice-growing experience. Overall, NERICA yield is 2.55 ton/ha, which is more than twice as high as the average upland rice yield in SSA. It is remarkable to find that there is such a large difference in yield between rice-growing experience households (REHs) and non-rice growing experience households (NREHs), viz., 2.83 and 1.97 ton/ha, respectively, indicating that experience does

⁵ Even if we use land per adult equivalent measures instead of land size per person, we find a similar relationship between land scarcity and income ranks. This relationship is also observed in the RePEAT survey where the average land size per adult equivalent among poor households is 0.9 ha while that among nonpoor households is 1.8 ha.

Table 10.2 NERICA yield per hectare by cropping pattern in second crop season in 2004

	All households	Rice experienced households	Non-rice experienced households
	(1)	(2)	(3)
Average in 2004 (2nd Season)	2.55 (1.48)	2.83** (1.35)	1.97 (1.57)
Previous crop:			
Export crop	3.30** (1.26)	3.30 (1.29)	3.29 (1.13)
Legume crop	2.81 (1.50)	3.16** (1.14)	1.96 (1.77)
Cereal crop	2.26 (1.67)	2.43 (1.51)	2.01 (1.88)
Fallowed/virgin land	2.37 (1.30)	2.67** (1.32)	1.84 (1.11)
Positive fertilizer use plot	2.46 (1.97)	2.99 (2.01)	1.96 (1.87)
Plot planted late ^a	0.95** (0.94)	1.01 (0.74)	0.92 (1.07)
Plot with steep slope	2.18 (1.61)	2.66* (1.24)	1.66 (1.82)
Plot is owned by HH	2.62 (1.49)	2.97** (1.37)	1.99 (1.48)

In column (1), * and ** indicate that average yield given management practice is statistically different from overall average yield (2.55) at 5% and 1% significance levels, respectively

In columns (2), * and ** indicate that the differences in means between REHs and NREHs are statistically different at 5% and 1% significance levels, respectively

^aFollowing the SG2000 guideline, late planting is defined as planting later than September 15 for the second cropping season

matter in achieving high yields.⁶ As is clear from Table 10.2, the yield is lower when NERICA was planted after cereal, indicating that the continuous cropping of cereal crops depletes soil nutrients, thereby reducing the sustainability of such a cropping system. This supports Hypothesis 3 on the importance of soil fertility in the adoption of new crop varieties. Another way to manage soil nutrients is to grow leguminous crops since it is known that leguminous crops have the capacity to fix nitrogen. Given the cropping pattern of cultivating leguminous crop before NERICA, we find that REHs obtained higher yield than NREHs. It is probably because REHs learnt from their experience and know more effective ways to utilize crop rotation by using leguminous crops than NREHs. Rice cultivation experience and cropping patterns significantly affect the NERICA yield even after controlling for the other variables in regression model (Kijima et al. 2006).

⁶This is confirmed by recent study on NERICA adoption in Uganda (Kijima et al. 2010).

10.3 NERICA Adoption

Since the effect of NERICA on household income depends on the size of land under NERICA, we first analyze the determinants of the absolute area, as well as the share of land area, planted to NERICA. Even if a new technology has great potential to increase farmers' income substantially, it may not be adopted due to a variety of reasons such as credit constraints, aversion to risk, and limited family labor availability (Feder et al. 1985; Dalton 2004). As with the existing literature (Munshi 2004; Conley and Udry 2001; Foster and Rosenzweig 1995; Besley and Case 1994), this study focuses on the role of access to information in the diffusion process of a new technology. This is because NERICA has only recently been released, and many farmers still do not have much information about it (Kijima and Sserunkuuma 2011, forthcoming). To adopt NERICA, farmers need to obtain the relevant information first. Thus, we hypothesize that accessibility to information is a crucial determinant of adopting NERICA, especially at the initial stage of the diffusion process.

We use two variables to proxy accessibility to information. One is a dummy variable of whether a household member belongs to any farmers' organizations or groups. Since group members tend to gather new information regularly and exchange their experiences, it is expected that membership to such groups enhances access to information on NERICA. The other variable is the years of formal education of the household head. This is because educated farmers tend to have greater ability to decode new information such as that obtained from printed material distributed by extension agents and NGOs (Schultz 1975).

Since most Ugandan farmers have never planted rice, rice cultivation in general may be considered riskier than other food crops, and this may deter NERICA adoption. However, for farmers who have experienced growing rice, the risk of crop failure may be lower, thereby increasing the probability of adopting NERICA. Therefore, we hypothesize that rice-growing experience has a positive effect on NERICA adoption. Following the methodology in previous technology adoption studies, we examine the determinants of the probability of adopting NERICA by using the Probit model.

It is also important to determine whether the availability of land, capital, and labor limits the expansion of NERICA cultivation. We analyze the area of NERICA production (to measure the extent of adoption) using the Tobit model since the dependent variable is censored at zero for non-adopters. Besides accessibility to information, we include village dummies as explanatory variables in the adoption regressions since climate, soil, external interventions, and rice production experience vary across villages.

The estimation results for the NERICA adoption function are provided in Table 10.3. In column (1), we estimate the probability of adopting NERICA using the Probit model and the figures indicate marginal effects. The determinants of the absolute area planted to NERICA using the Tobit model are examined in column (2). Column (1) shows that the proxy variables for accessibility to information,

Table 10.3 Determinants of NERICA adoption^a

	Pr (adopt =1) [Probit]	Area planted to NERICA (ha) [Tobit]
Dummy for a member of a non-rice farmer's group (=1 if yes)	0.192*** (5.10)	0.302*** (5.23)
Dummy for experience of growing non-NERICA rice (years)	0.236*** (5.76)	0.054*** (6.98)
Household head's formal education (years)	0.016*** (3.57)	0.011* (1.76)
Household head is female (=1 if yes)	-0.080** (2.08)	-0.089 (1.23)
Household head's age (years)	0.002 (1.46)	-0.001 (0.84)
Number of household members	0.019*** (3.57)	0.039*** (5.51)
Proportion of members who are male adults aged 15–59	0.072 (0.69)	0.157 (0.95)
Proportion of members who are female adults aged 15–59	-0.038 (0.39)	-0.155 (1.03)
Land size per person (ha)	-0.001 (0.44)	0.068* (1.73)
Value of livestock (\$1,000)	0.006 (0.27)	0.049 (1.37)
Value of household asset (\$1,000)	-0.011 (0.44)	0.006 (0.19)
Traveling hours to rice miller by common means of travel	0.004 (0.19)	0.005 (0.13)
Constant		-0.744*** (4.76)
Village dummies	Yes	Yes
Observations	400	400
Log likelihood	-80.9	-243.1
R-squared (pseudo r-squared)	(0.55)	(0.33)

^a** Significant at 10%, ** significant at 5%, *** significant at 1%. Columns (1): Numbers in parentheses are *z*-statistics. Numbers are marginal effects, not estimated coefficients. Columns (2): Numbers in parentheses are *t*-statistics

i.e., membership to a farmer's group and the formal education of the household head, significantly increase the probability of adopting NERICA, which supports our hypothesis. As expected, households with non-NERICA rice-growing experience are more likely to adopt NERICA. While the number of household members has a positive and significant effect, livestock assets, household assets, and the total land area per household member do not have a significant effect. These findings are reasonable because NERICA production is labor intensive but not intensive in the use of other inputs.

The results for the area planted to NERICA (column 2) are qualitatively similar to those for the probability of adopting NERICA discussed above; i.e., rice-growing experience, membership in a farmer's group, and formal education increase the scale of area planted to NERICA. The estimation result of the determinants of area planted to NERICA indicates that households with more family labor adopt NERICA on a larger scale. Thus, it is clear that the availability of family labor constrains the size of area planted to NERICA.

10.4 Impacts on Crop Income

To assess the impacts of NERICA adoption on income, we first need to know whether there is selection bias; in other words, whether the error terms in NERICA adoption and the yield functions are correlated. This is because it is possible that NERICA adopters are more capable than non-adopters in farming, which would bias the estimation results of the NERICA yield function. If these error terms are correlated, we need to correct such a bias in the NERICA yield function by the Heckman model. However, statistical tests found that these error terms are not correlated, and therefore we estimate the plot-level income from NERICA and the alternative crops by OLS.⁷

The household income from crop production is determined not only by technology and factor endowments but also by management practices, which may be reflected in the cropping patterns. We expect that the choice of a certain cropping pattern tends to be correlated with the plot-specific characteristics such as soil fertility and the farmer's unobserved management ability. Our strategy to identify the pure effects of NERICA adoption on household income is (1) to obtain information from two plots (NERICA and the alternative crop),⁸ which are located in the same parcel and are located nearby each other, and (2) to estimate the crop income function by the household fixed-effects (FE) model, which eliminates the effects of the remaining unobserved plot and household characteristics.

The empirical model is specified as follows:

$$y_{sji} = \gamma Z_{sji} + \delta H_{ji} + \beta X_i + u_i + \varepsilon_{sji},$$

where y_{sji} is the crop income from plot s (subscript N refers to the NERICA plot and O to the other crop plot) at parcel j of household i , Z_{sji} is a set of characteristics of plot s at parcel j of household i , H_{ji} is a set of characteristics of parcel j of household i , X_i is a set of household i 's characteristics, u is the household's FE, and ε is an error term.

⁷The results of the Heckman model are obtained from Appendix Table 1 of Kijima et al. (2007).

⁸If there are many plots in the NERICA parcel, we selected the maize plot. If there is no maize plot, then we picked the legume plot. If there is neither a maize nor a legume plot, we selected a roots/tuber crop plot.

Table 10.4 Estimation results of the plot-level income function (USD/ha), household fixed-effects model^a

	Coefficient	(<i>t</i> -stat)
Cropping patterns ^b (previous crop–current crop)		
Cereal – NERICA	452***	(3.34)
Legume – NERICA	500***	(3.17)
Roots/ Tubers – NERICA	488*	(2.14)
Tobacco – NERICA	605***	(3.67)
Virgin – NERICA	670***	(3.67)
Fallow – NERICA	339**	(2.20)
Size of the plot (ha)	–154	(1.35)
Chemical fertilizer application (kg/ha)	58.4***	(2.57)
Intercropping (=1 if plot is intercropped)	17.9	(0.20)
Constant	–58.9	(0.12)
Number of observations	490	
R-squared	0.62	

All the means and proportions are *calculated* with sampling weights

* Significant at 10%, ** significant at 5%, *** significant at 1%

^aNumbers in parentheses are *t*-statistics

^bThe default of the cropping pattern is non-rice cereal–non-rice cereal. The other cropping pattern dummies included are cereal–legume, legume–legume, roots–legume, tobacco–legume, virgin–legume, fallow–legume, cereal–roots, legume–roots, roots–roots, tobacco–roots, virgin–roots, fallow–roots, legume–cereal, roots–cereal, tobacco–cereal, virgin–cereal, fallow–cereal. The coefficients of these cropping pattern dummies are not significant

The inclusion of the FE controls for households' unobserved characteristics such as farming ability. The plot characteristics include the size of the plot, the crop planted in season t , the plot use in the previous season ($t - 1$), and whether the plot is planted in pure stand or intercropped.

Table 10.4 exhibits the estimation results of the plot-level crop income functions. As the bottom of the table indicates, the number of observation is less than 500 (2 plots $\times$ 250 households) since we lack information to calculate income from alternative crop plots in five households. Thus, the total sample size for the plot-level regression analyses becomes 490 (2 plots $\times$ 245 households). Although income pertains to current-season crop income only, previously grown crops are specified. The results show that the income from the NERICA plot is significantly higher than the income from other cereal/food crops (comparison group is cereal–cereal). The income is higher on plots previously fallowed or uncultivated as well as those planted to leguminous crops, which have capacity to fix nitrogen or tobacco to which large amount of inorganic fertilizer is applied, suggesting that the NERICA yield is highly responsive to soil fertility. This finding is consistent with Hypothesis 3, specified in Chap. 1, that soil fertility affects the choice of technologies.

One may argue that higher yields associated with the tobacco–NERICA rotation cannot be accessible to all farmers since tobacco-growing households have a larger labor pool to draw from than nontobacco-growing households. At least in our sample, however, this is not the case. There are no significant differences in cultivated

land size per adult-equivalent household members, the number of male adult members, and the number of female adult members between tobacco-growing and nontobacco-growing households. However, the tobacco–NERICA cropping pattern may not be adopted in some areas since tobacco is likely to be adopted where a tobacco company (British American Tobacco) offers credit and contract farming in Uganda

10.5 Impact on Poverty and Income Distribution

In order to evaluate the effect of an intervention on household income, several analytical techniques could be used such as difference-in-difference (DID) estimation, propensity score matching, and randomized experiments (Ravallion 2005). We attempted to compare the areas with non-NERICA upland rice and the areas with NERICA using DID estimation. However, in areas where non-NERICA upland rice was cultivated, most of the households had already switched to NERICA, and thus we could not find such controlled areas. In addition, we could not conduct randomized experiments since the government program disseminated NERICA in a non-random way, and it was too costly for the research team to establish its own randomized experiment. Regarding the propensity score matching, Heckman et al. (1998) demonstrate that failure to compare participants and controls at the common propensity score is a major source of bias in evaluations. Besides, the NERICA survey sample was drawn by stratified random sampling, which does not suit the application of the propensity score matching technique. Thus, for this chapter, we conduct simulation analyses by estimating the household's hypothetical income in the absence of NERICA, under a range of alternative scenarios. We believe that this analysis provides valuable information even with its strong caveats and limitations.

In the simulation analyses, we estimate the hypothetical income of a household if NERICA had not been adopted. We call this hypothetical income “without NERICA.” For this scenario, we assume that households would grow the alternative crop on the NERICA plot if NERICA had not been introduced. For example, if tobacco was planted in the first cropping season and a legume crop was planted as the alternative crop on the adjacent plot in the second cropping season, we assume that the cropping pattern on the NERICA plot would have been tobacco–legume, rather than the currently observed tobacco–NERICA. Using the estimated coefficients from the crop income model, the net gain or loss of income from growing NERICA compared with the alternative crop is estimated for each household. Since the area planted to NERICA differs across households, the actual increment of income due to NERICA production is also adjusted by the size of the NERICA plot.⁹

⁹In our analyses, the prices are assumed to be constant. Given that rice is imported in Uganda, the domestic price is essentially determined by the international price. Because of this, we think that setting the rice price constant for the simulation is not an unrealistic assumption, even when rice production increases as NERICA becomes widely adopted in Uganda.

In our assessment of the impact of NERICA adoption on income, we do not consider its impact on nonfarm income. An implicit assumption of our estimation method is that there are no nonfarm job employment opportunities for marginal units of farm labor in our study sites. Given the limited nonfarm employment opportunities, this assumption seems justifiable. However, to the extent that family labor could be reallocated from nonfarm to farm activities, our estimation leads to overestimation of the impact of NERICA.

Some may argue that examining poverty and income distribution among NERICA adopters is not appropriate since this simulation does not take into account the possibility that adopters may obtain higher yields than non-adopters (Dalton 2004) and, hence, the former tend to be wealthier than the latter (Whitehead 2006; Little et al. 2006; Peters 2006). To show that the sample of NERICA adopters has an income distribution similar to the sample of the representative household survey, we tested whether the distributions of the per capita income in the households of the NERICA survey and in the RePEAT survey are equal by the Kolmogorov-Smirnov test (K-S test, hereafter). The K-S test cannot reject the null hypothesis that the two distributions are equal at a p -value of 0.189. Thus, our simulation analyses using the NERICA survey data can be justified. Kijima et al. (2007) provide further details on this test.

Once the hypothetical income is estimated, we calculate the average per capita income, poverty measures, and inequality measures. As poverty measures, the head count ratio (HCR), poverty gap index (PGI), and squared poverty gap index (SPGI) are estimated. As inequality measures, we calculate the Gini coefficient and the Theil index.

Table 10.5 shows the simulation results on the poverty and inequality measures within the sample areas. We use the coefficients of Table 10.4 to evaluate the effect of cropping patterns on crop income. The hypothetical income

Table 10.5 Actual and hypothetical income distribution and poverty incidence with and without NERICA production^a

	Income	
	Actual	Hypothetical ^b
Per Capita Income (USD)	161	141
(s.d.)	(139)	(131)
Poverty Line=USD 128 ^c		
Head Count Ratio (HCR)	49.1	54.3
Poverty Gap Index	23.0	30.4
Squared Poverty Gap Index	14.5	22.4
Inequality measures		
Gini coefficient	0.411	0.443
Theil Index	0.290	0.332

^a All the means and proportions are calculated with sampling weights

^b The hypothetical income is estimated by assuming that an alternative crop had been grown on the NERICA plot. The hypothetical income is the income if NERICA was not introduced

^c The poverty line calculated in Yamano et al. (2004) is adjusted to the 2005 price level by using the CPI given in UBOS (2005)

(without NERICA adoption) is smaller than the actual per capita income by \$20 on average. Poverty among sample farmers decreased from 54.3% to 49.1% due to the introduction of NERICA.¹⁰ Not only the HCR but also the PGI and SPGI decline due to the introduction of NERICA, suggesting that its income enhancement can be realized among the poorest of the poor.

Estimated inequality measures, the Gini coefficient and the Theil index, show that the actual income distribution with NERICA is more equitable than the hypothetical income distribution without NERICA. This is because poorer households plant NERICA on a larger proportion of their cultivated land and use more labor on NERICA production.

10.6 Conclusion

This chapter has examined the effect of new farm technology on the income of poor farmers in SSA using the case study of NERICA in Central and Western Uganda. NERICA has the potential to increase per capita income by \$20 (12% of actual per capita income) and to decrease the poverty incidence, measured by the head count ratio, by 5% points. These results support Schultz's hypothesis that introducing a new profitable technology in traditional agriculture is an effective strategy to reduce poverty (Schultz 1964, 1979). Such a positive effect of NERICA, however, can only be realized when its adoption is combined with the use of appropriate cropping patterns to maintain soil fertility. These results suggest that both the development of new high-yielding, labor-using technologies, and the effective extension and dissemination of technological knowledge about the new technologies are critical to enhance the income of poor farmers.

Since the amount of rainfall is high in most areas of the country, there is the potential for the countrywide diffusion of NERICA in Uganda. In addition, the price of rice is relatively high because of the land-locked nature of Uganda and the rapidly increasing demand for rice due to increasing urbanization and population growth. Unlike traditional cash crops such as tobacco and coffee, which are grown exclusively for cash income, rice is also home-consumed, implying that NERICA can also contribute to the improvement of household food security.

The current NERICA adoption rate, however, is estimated to be less than 1% at the national level, which seems to suggest the existence of serious constraints on the adoption of NERICA such as the shortage of NERICA seeds and ineffective extension services. Thus, while this study highlights the significant poverty-reducing effect of NERICA in areas where it has been adopted, this has yet to be realized in most parts of the country. Only if more effective NERICA dissemination programs are implemented, can NERICA contribute significantly to poverty reduction in Uganda.

¹⁰ The poverty line calculated in Yamano et al. (2004) is inflated up to the 2005 price level by using the CPI given in UBOS (2005).

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Chapter 11

On the Possibility of a Lowland Rice Green Revolution in Sub-Saharan Africa: Evidence from Eastern Uganda*

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Abstract This chapter attempts to provide better understanding of the impacts of demonstrations or training of improved lowland rice management practices on its diffusion and rice yields by using the case of the JICA program in Eastern Uganda. The most important finding of this study is that lowland rice yield can be extremely high in Uganda if basic production practices, such as bunding, leveling, and straight row planting, are adopted along with the adoption of modern rice varieties and the use of simple irrigation systems, even if chemical fertilizer is not applied. The major challenge is how to disseminate such a package of improved production practices to farmers. According to our analysis, the intensity of training participation is the key to the adoption of such practices. It was also found that training participation decreases as the distance from the demonstration plot increases.

Keywords Lowland rice • Cultivation practices • Diffusion of technology • Yield enhancement • Uganda

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11.1 Introduction

In contrast to the dramatic success in increasing agricultural productivity in Asia since the late 1960s, agricultural productivity has been largely stagnant in Sub-Saharan Africa (SSA) (Otsuka and Yamano 2005). Due to rapid population growth and urbanization, the consumption of rice has been increasing far more rapidly than its domestic production in SSA, thereby increasing the net import of rice (Africa Rice Center 2008). In addition, the sharp rise of cereal prices since 2008 has resulted in serious food insecurity among the poor in this region (Ivanic and Martin 2008; Benson et al. 2008). Given that rice is a major cereal crop, which has great potential for increasing its productivity in SSA, strategic efforts to enhance rice production are urgently needed not only for food security but also for income generation (Otsuka and Kijima 2010; Diao et al. 2008).

It is well known that the rice Green Revolution in Asia was led by the development of high-yielding modern rice varieties, irrigation investment, and the ample use of chemical fertilizer (Hayami and Godo 2005; David and Otsuka 1994). In SSA, however, irrigation investment by donors and government has been low due, partly to, the high costs of constructing irrigation facilities and partly to the mismanagement of past large-scale government-led irrigation projects (Inocencio et al. 2007; Fujiie et al. 2005; Kajisa et al. 2007). Further expansion of upland rice production is limited by weed problems and soil degradation caused by reduced fallow periods (Sakurai 2006). Recent rice area expansion in SSA has been concentrated in the rainfed lowlands where adequate water control has seldom been implemented (Dalton and Guei 2003). In addition, actual yields in the lowland ecosystem are much lower than the potential (WARDA 1999). In other words, rice production in rainfed lowlands is considered to have high potential for increasing rice production in SSA.

One of the reasons why yields of lowland rice are currently far lower than their potential in SSA is that many rice growers cultivate lowland rice without applying appropriate cultivation practices. In many countries, chemical fertilizer is so expensive that the demand is low. In some cases, seeds are broadcasted, which makes it difficult to remove weeds where no space is provided to walk in the field. Even when transplanting is adopted, seedlings tend to be too old, and straight-row planting is not implemented to facilitate weeding. Bunding and leveling are not properly practiced, so that water is not stored evenly in paddy fields. In order to achieve high productivity in lowland rice farming, JICA has initiated the Sustainable Irrigated Agricultural Development (SIAD) project in Eastern Uganda, which provides training of lowland rice cultivation practices based on the Asian experience.

This study attempts to understand the impacts of demonstrations or training of improved lowland rice management practices on its diffusion and rice yields by using the case of the JICA program. Specifically, we attempt to explore the effects of the training on the production performance by identifying the determinants of (1) participation in the training, (2) understanding of the recommended cultivation practices, (3) adoption of practices, and (4) yield enhancement. By doing so, we evaluate the bottlenecks of the JICA project, which need to be addressed in order to enhance rice productivity in the entire country as well as the potential for a lowland rice Green Revolution in Uganda.

The rest of this paper is structured as follows. [Section 11.2](#) describes the present state of lowland rice production in Eastern Uganda and the content of the JICA project. [Section 11.3](#) explains the sample data used in this paper and examines the descriptive statistics. In [Sect. 11.4](#), the estimation models on participation in the training, adoption of new cultivation practices, understanding of training materials, and rice yield are introduced and the estimation results are presented. The last section concludes the chapter with policy implications.

11.2 Lowland Rice Production in Eastern Uganda and the SIAD Project

11.2.1 Lowland Rice Production in Eastern Uganda

In Uganda, about 10% of the country is covered by wetlands or swamps at the base of valleys bottoms (FAO 2006), which are particularly suitable for lowland rice production. In fact, rice is one of the few profitable cash crops grown in lowlands in such areas. In Eastern Uganda, lowland rice cultivation technology and modern rice varieties were introduced in the 1970s by the Chinese in the Kibimba Rice Scheme and Doho Rice Scheme (FAO 2006).¹ Since then, unutilized swamps (normally covered by papyrus) have been rapidly converted to lowland rice fields.

The modern variety of rice developed by the International Rice Research Institute (IRRI) was crossed with local varieties. Improved varieties “K5” (rice variety from Kibimba) and “supa” (meaning rice) are widely adopted in lowland areas in Eastern Uganda. It is said that while the origin of K5 was one of the early modern varieties developed by IRRI, the origin of supa is less clear. In upland areas, sweet potato, maize, and cassava are grown for self-consumption.

Eastern Uganda is located in a bimodal rainfall zone, and farmers in the irrigation schemes are engaged in the two-season double-cropping of rice (Nakano 2010). In many rainfed lowlands, unless rainfall is too low, double-cropping of rice is common.

11.2.2 SIAD Project

The objective of the JICA project is to increase rice production and productivity by introducing sustainable rice cultivation practices widely adopted in Asia as well as simple small-scale irrigation infrastructures. The project covers 22 districts in

¹In the 1970s the Chinese initiated the development of rice schemes, with the Kibimba rice scheme (600 ha) as a rice technology development scheme and the Doho rice scheme (1,000 ha) for seed multiplication and popularization of production. These areas are still major rice production areas in Eastern Uganda.

Eastern Uganda and is scheduled to be implemented from July 2008 to June 2011. The training starts by phase: the first cropping season of 2009 (called Group A in 10 districts), the second cropping season of 2009 (Group B in 5 districts), and the first cropping season of 2010 (Group C in 7 districts).

In each district, one project site is selected. The selection of sites is not random since lowland rice cannot be grown in upland areas. Indeed, all the project sites are wetlands with seasonal or year-round springs and streams. In addition to this geographical condition, the formation of rice farmers associations was required as one of the conditions for implementing the project. Thus, it is reasonable to assume that farmers in the project sites tend to be more motivated and to have relatively more favorable access to water than the average Ugandan farmer and the sites selected by JICA are more or less similar in terms of environment for lowland rice cultivation.

Training is provided to the district agricultural officers (DAO), extension workers, and lead farmers with a view to disseminating basic knowledge on rice cultivation practices and small-scale irrigation management through face-to-face communications. JICA experts and extension workers provide field training to farmers on demonstration plots in each project site, which range from 0.2 to 0.4 ha. Training consists of four parts: (1) establishing the demonstration plot and constructing an irrigation canal in the surrounding area [2–3 weeks]; (2) preparing nursery beds, planting to the nursery beds, and leveling [half day]; (3) transplanting and weeding [half day]; and (4) harvesting and threshing [half day].

JICA sets up the demonstration plot and builds the irrigation canal connecting the demonstration plot with a water source. Farmers have to construct their own irrigation canals with guidance and help from JICA by digging the ditches using hand hoes. There are no devices for metering the intake of water into individual fields. Even though the title of the project includes the term “irrigation,” this project does not construct modern irrigation facilities, which are expensive to construct and maintain. This is because JICA experts believe that even if modern irrigation systems are constructed, the productivity of rice cultivation cannot be enhanced significantly without proper cultivation practices. Thus, only simple irrigation facilities are promoted by the JICA project.

11.3 Data

11.3.1 Sampling

Among Group A locations, five districts have had similar projects since 2005. To capture the midterm impact of the training project, we sampled two sites from Group A (namely Bugiri and Mayuge, where the water source is seasonal streams). Although we failed to obtain pre-project information at these two sites, we collected such information at new sites (namely, Pallisa and Bukedea, where the water source is year-around springs), in which training started just prior to the data collection. The data on yields and cultivation practices in the previous seasons were collected. Thus, the adoption of cultivation practices and rice yields have not been affected by

the JICA training in these new sites. By using this difference in starting time of training, we attempt to measure average treatment effect of the training including the spillover effect from training participants to nonparticipants where the new sites are control group and the other two sites are treatment group.

In each site, 75 households were selected based on the distance from the demonstration plot to each household's rice plot to capture the diffusion process beginning from the demonstration plot.²

11.3.2 Descriptive Statistics

Table 11.1 shows the participation status in the JICA training by project site. In Bugiri, just after JICA started training, the number of training participants was large and by the end of 2007, 70% of the sample households had taken part in the training

Table 11.1 Participation in JICA training

	Bugiri	Mayuge	Pallisa	Bukedea
Number of sample households	75	75	75	75
Year JICA training started	2005	2005	2009	2009
No. of HH that participated in JICA training for the first time in 2005	30	9	0	0
No. of HH that participated in JICA training for the first time in 2007	20	11	0	0
No. of HH that participated in JICA training for the first time in 2008	3	5	0	0
No. of HH that participated in JICA training for the first time in 2009	0	4	15	25
Percentage of households with:				
No participation	29.3	61.3	66.7	80.0
1–5 training days	42.7	26.7	24.0	14.7
5–10 training days	22.7	12.0	9.3	5.3
10–20 training days	5.3	0.0	0.0	0.0
Number of nonparticipants in JICA training	22	46	60	50
% of nonparticipants who did not know about demonstration plot	27.9	8.8	19.8	14.0
Reason why did not participate in JICA training (% among non-participants)				
Did not know	68.9	45.5	83.1	78.7
Not interested	15.6	40.9	11.9	21.3
Busy	13.3	9.1	3.4	0.0
Did not have money to pay to join association	2.2	4.6	1.7	0.0

²Sample lowland areas are oval shape with one long diameter and the other of short diameter. Along the short diameter, there are 6–10 plots. One plot was selected randomly approximately at 25 m intervals from the demonstration plot in both directions along the long diameter. Half of the plots are rented in land and 70% of them were rented before 2008.

Table 11.2 Rice yield in 2007–2009

	All	Bugiri/Mayuge	Bukedea/Pallisa		Bugiri	Mayuge	Bukedea	Pallisa
2005	3.08 (2.52)	3.60 (2.72)	1.77 (1.11)	*	3.98 (2.96)	2.72 (1.81)	1.40 (0.94)	2.10 (1.16)
2007	2.65 (2.85)	3.50 (2.98)	1.52 (1.03)	*	4.64 (3.35)	2.17 (1.71)	1.31 (0.98)	1.61 (1.06)
2008	2.65 (2.83)	3.40 (2.79)	1.43 (1.46)	*	4.75 (2.80)	2.32 (2.90)	1.35 (1.51)	1.56 (1.40)
2009	2.50 (2.61)	3.02 (2.78)	1.35 (1.69)	*	4.03 (3.21)	1.82 (1.43)	1.29 (1.89)	1.46 (1.26)

* indicates that the difference in yields between treatment districts and control districts is statistically significant at the 5% level

at least once. In contrast, the training participation rate was lower in Mayuge and it was only 35% by 2007. This low participation rate was not due to the lack of information about the JICA's demonstration project by nonparticipants. In the case of the Mayuge site, 41% of the nonparticipants answered that they were not interested in the training. The intensity of training received among the participants is also quite different. In Bugiri, 28% of the sample farmers attended the training for more than 5 days. The difference in training intensity is likely to result in a different effect of training on the comprehension of what was taught in the training sessions.

The trend of yields over time is shown in Table 11.2. In normal years (i.e., 2007 and 2008), the average rice yield is about 2.7 ton/ha. The yield in the new sites (Bukedea and Pallisa) is significantly lower by 2 ton/ha than that in Bugiri and Mayuge where JICA provided training since 2005. Since there is no data on preprogram yield in Bugiri and Mayuge, it is not possible to show the difference in yields before and after the training in the area. It is, however, likely that situation in the new sites was similar to that in Bugiri and Mayuge before JICA started the training.

In Bugiri, the average rice yield reached 4.7 tons in one season, while in new sites, the yield was lower at 1.3–1.6 tons. The yield in Mayuge fell somewhere in between. The superior performance of Bugiri may be due to the fact that Bugiri has an irrigation structure, which covers 10 ha constructed by JICA. In addition, farmers voluntarily constructed canals between the water source and farmers' fields. The yields are, however, not significantly different between fields irrigated by the farmers and by the JICA scheme (in 2009, 4.05, and 3.99 ton/ha, respectively). This finding suggests that simple irrigation facilities constructed by farmers significantly improve the efficiency of rice farming.

Does the low participation rate and low interest in training among potential beneficiaries mean the failure of the JICA project in Mayuge? Why was the number of participants large in Bugiri from the beginning? One of the answers to these questions might be the difference in the returns to the training participation in these sites. Table 11.3 shows the average rice yield before and after the training among the training participants and the yield among the non-participants (without program). In Bugiri, rice yields increased significantly from 5.4 tons to 7.0 tons after the training was introduced in 2005. Since the average rice yield in tropical Asia is lower than

Table 11.3 Rice yield (ton/ha) before and after the training by district

First year of training	Participants				Nonparticipants			
	Before	<i>t</i> -Test ^a	1 year after (with)	<i>t</i> -Test ^b	Before	<i>t</i> -Test ^c	1 year after (without)	DID ^d
<i>Buguri</i>								
2005	5.36	*	7.03	*	2.73	*	3.96	
2007	4.56		4.85		3.14	*	4.22	*
2008	4.18		3.35		4.22		2.84	
<i>Mayuge</i>								
2005	2.90		1.91		2.66	*	2.21	
2007	2.69		2.91		2.12		2.52	
2008	1.61		1.37		2.10		1.85	

^a* indicates that the difference in yields before and after the JICA training for those who participated in training (treatment group) is statistically significant at the 5% level

^b* indicates that the difference in yields with and without the JICA training before training is statistically significant at the 5% level

^c* indicates that the difference in yields before and after the JICA training for those who did not participate in training (control group) is statistically significant at the 5% level

^d* indicates that the difference between treatment and control groups in difference in yields before and after the JICA training are statistically significant at the 5% level

4 tons per ha, these yields are extremely high, suggesting the strong potential for a rice Green Revolution in Uganda. On the other hand, in Mayuge there was no significant increase in rice yields after the training in 2005 and 2006. This difference in the effect on rice yields may explain why farmers in Mayuge were not interested in participating in the training. It is important to note that during the first cropping season of 2009 there was a serious drought, in which the impact of improved production practices tends to be weak. That is why the rice yield after training was dropped for those who participated in the training in 2008 for the first time.

Table 11.4 shows the rice yield separately by the number of new improved cultivation practices actually adopted between September 2008 and August 2009. It is clear that the average yield is higher as more practices are introduced. In Bugiri, the yield was 4.5 ton/ha when 4 practices were adopted, while that with 1 practice was only 2.3 ton/ha. Such substantial difference in yield may suggest that there are complementarities among the improved cultivation practices. There are no clear relationships between the number of practices applied and yield in the new sites, which may indicate that farmers applied them incorrectly since they had not received trainings yet.

Table 11.5 describes the availability of water in the rice plots. In Bugiri and Mayuge, water is supplied through irrigation canals to most of the rice plots. In the new sites (Bukedea and Pallisa), 21% of the plots have wells in the plots. In Bukedea, water flows into the plots directly from neighboring plots without irrigation canals in 68% of the plots. The yield tends to be higher when water flows into the plot from irrigation canals and there is a well in the plot than that without them. Another measure of water availability is the farmers' subjective judgment. Farmers were asked about the moisture status of the soil at the flowering stage when the availability of water critically affects the yield. The table shows that about 20% of the plots were dry at the flowering stage

Table 11.4 Yield by cultivation practice adoption in September 2008–August 2009

	All	Bugiri	Mayuge	Bukedea	Pallisa
4 Practices ^a	4.13 (3.14)	4.47 (3.20)	2.89 (1.83)	1.22 (0.74)	0.37 – ^b
3 Practices ^c	3.20 (2.78)	4.15 (3.17)	1.89 (1.31)	–	1.54 (1.14)
2 Practices	2.25 (1.75)	3.07 (3.44)	2.00 (1.44)	3.95 (1.40)	2.26 (1.09)
1 Practice	1.81 (1.43)	2.30 (0.80)	1.91 (1.13)	1.89 (1.87)	1.38 (1.23)
Non-adopters	1.33 (1.99)	–	0.79 – ^b	1.42 (2.10)	0.66 (0.56) ^d
Fertilizer Use	7.55 (2.28) ^e	7.55 (2.28) ^e	–	–	–

^a 4 practices = bunding, leveling, proper timing of transplanting, straight-row planting^b Only 1 observation^c 3 practices = among 4 practices, 3 practices were implemented^d Only 3 observations^e Only 4 observations**Table 11.5** Water availability in September 2008–August 2009

	All	Bugiri	Mayuge	Bukedea	Pallisa
<i>% of plots where</i>					
Water comes through irrigation canal	71.0	95.4	79.1	10.6	53.6
Well in the plot	5.9	0.0	0.0	21.3	21.4
Water flows through neighboring plots	23.1	4.6	20.9	68.1	25.0
<i>Yields (ton/ha)</i>					
Water comes through irrigation canal	3.16 (2.76)	4.17 (3.21)	2.10 (1.44)	0.84 (0.75)	1.75 (1.00)
Well in the plot	1.79 (1.54)	–	–	1.51 (1.52)	2.26 (1.59)
Neither	1.88 (1.97)	4.42 (2.20)	1.57 (1.02)	1.81 (2.24)	1.19 (1.14)
<i>Subjective water availability (%)</i>					
Flowering stage: with water	49.8	54.6	46.5	46.8	46.4
Flowering stage: wet	29.7	26.9	29.1	36.2	32.1
Flowering stage: dry	20.4	18.5	24.4	17.0	21.4
Controlling water at flowering stage	53.2	60.2	57.0	23.4	64.3
<i>Yield</i>					
Plot with water at flowering stage	2.93 (2.37)	4.13 (2.73)	1.71 (0.87)	2.33 (2.33)	2.32 (1.15)
Dry plot water at flowering stage	2.26 (2.49)	3.53 (3.35)	1.84 (1.31)	1.23 (1.95)	0.85 (0.95)

and 53% of the households actually controlled the water intake at this stage. The yield in the plots with water at the flowering stage is much higher than in those without water. However, the difference is not significant, probably because the drought negatively affected the plots even with water at the flowering stage as well.

11.4 Model and Results

11.4.1 *Participation in Training*

To increase the effectiveness of the training, it is important to know what determines the participation in such training sessions. For the Bugiri and Mayuge sites, it is difficult to examine this properly since we do not have preprogram data. For the new sites (Bukedea and Pallisa), we can assess more accurately the determinants of participation in the training.

Since farmers whose plots are closer to the demonstration plot and who belong to farmers groups are expected to have better access to information about training through geographical and social networks among farmers, their participation rates in the training are expected to be higher. Thus, whether households participate in the training or not is assumed to be a function of the distance from the demonstration plot to one's plot and the social network that the household has access to. The dependent variable is the number of training days that households had participated in between August 2009 and September 2009, the first 2 months of the program in the new sites. The explanatory variables reflect conditions in September 2008. This model is estimated by OLS.

Table 11.6 shows the estimation results. In the new sites, the number of training days participated in is mainly determined by the distance from the demonstration plot but not by the number of groups that a household belongs to. This is expected since the program had just started in new sites and JICA was preparing to expand the number of training participants by offering training sessions to neighboring households during the rest of the program period. After the effect of training becomes apparent among the training participants and the information about the positive effect of the training is shared with the nonparticipants, the distance to the demonstration plot may become an insignificant determinant of participation in the training.

11.4.2 *Does Training Enhance the Understanding of the Improved Production Practices?*

Examining what enhances the understanding of the cultivation practices is an important first step in the adoption of proper practices. Otherwise, the training cannot be effective. It is reasonable to postulate that the degree of understanding the material is higher when the participation period is longer and farmers are more educated. To analyze this rigorously, we run a regression model.

To measure the degree of knowledge about cultivation practices by farmers, sample farmers were asked to take a simple quiz about rice cultivation. This quiz was placed on the last page of the questionnaire so that it would not affect the responses in the rest of the questionnaire. The quiz consisted of one question each on the importance of conducting leveling and using sufficiently young seedlings for

Table 11.6 Determinants of number of training days participated (OLS)

	Bukedea	Pallisa
	(1)	(2)
Distance from demonstration plot (km)	-1.136 (3.65)***	-0.168 (3.57)***
Number of farmers groups belonged to	-0.267 (1.26)	0.023 (0.55)
Year started cultivating lowland rice	-0.008 (0.63)	-0.003 (1.15)
Moved to this area after 2000 dummy	0.305 (1.26)	0.030 (0.67)
Female-headed household dummy	0.080 (0.21)	0.057 (0.46)
Land owned (ha)/number of adult family members (age 15–64)	0.292 (1.28)	0.081 (1.67)*
Initial assets (household, agricultural, livestock) (USD)	0.000 (0.86)	0.000 (0.22)
Household head's age	0.036 (2.54)**	-0.000 (0.27)
Household head's years of education	-0.018 (0.50)	0.015 (2.24)**
R-squared	0.69	0.68
Observations	52	75

Household-level data

* Significant at 10%; ** significant at 5%; *** significant at 1%

transplanting. In the model, the dependent variable takes unity when households answered each quiz question correctly and zero otherwise. The data show that the percentages of sample households that answered the quizzes on leveling and seedling age for transplanting correctly are 40% and 62%, respectively. There is a positive relationship between correctly answering the questions and the number of training days.

To measure the training intensity, which is an important explanatory variable, we use the number of training days accumulated by the time we conducted the quiz with the farmers. This means that this variable takes nonnegative values in the new sites since some farmers had participated in the JICA training just before the data collection. Since the more able farmers tend to seek training opportunities and such farmers would have performed better on the quiz than the nonparticipants, even when they would not have participated in the training, the training participation variable can be endogenous. To correct the bias arising from the simultaneity, the instrumental variable Probit estimation model is applied, where the distance from the demonstration plot to one's rice plot is used as an instrumental variable for the training participation variable.

Table 11.7 exhibits the estimation results, where the estimated coefficients show marginal effects. In the first column, the dependent variable is a binary variable representing whether a farmer answered the question on leveling correctly or not. In the second column, the dependent variable takes unity if farmers answered the

Table 11.7 Effect of training on understanding the technology (household level, IV probit, marginal effects)

	Leveling (1)	Seedling age (2)
Number of training days ^a	0.119 (1.89)*	0.147 (2.17)**
Member of non-rice association	0.034 (0.21)	0.461 (1.23)
Year started cultivating lowland rice	0.015 (1.23)	−0.062 (0.34)
Moved to this area after 2000 dummy	−0.119 (0.63)	−0.211 (0.13)
Female-headed household dummy	−0.344 (0.86)	1.850 (2.19)**
Land owned (ha)/number of adult family members (age 15–64)	0.228 (1.40)	0.198 (0.42)
Initial assets (household, agricultural, livestock) (USD)	−0.000 (0.19)	0.000 (1.01)
Head's age	0.004 (0.55)	0.006 (0.82)
Head's years of schooling	0.003 (0.15)	0.051 (2.03)**
Bugiri	−0.429 (1.68)*	−0.727 (2.57)***
Pallisa	−0.141 (0.51)	−1.247 (2.18)**
Bukedea	−0.040 (0.15)	−0.888 (0.41)
Number of observations	276	276

* Significant at 10%; ** significant at 5%; *** significant at 1%

^aTraining participation=endogenous, instrumented by distance to demonstration plot. z-Statistics are in parentheses

question on the appropriate seedling age for transplanting correctly and is zero otherwise. In both columns, participation in the training increases the probability of answering correctly the questions on cultivation practices taught in the training. The estimated marginal effect of the training suggests that one additional training day increases the probability of correctly answering the question by 12–15%. Thus, it is desirable to provide training repeatedly to farmers in order that they acquire the appropriate production knowledge.

11.4.3 *Effect of Training Participation on the Adoption of Cultivation Practices*

Whether the recommended cultivation practices are adopted or not should be affected by the household characteristics such as access to information, rice cultivation experience, and asset holdings, as well as plot characteristics such as water

availability and land tenancy. As shown in the previous subsection, participation in JICA training enhances the knowledge regarding the improved production practices, which is expected to increase the adoption rate. Even without the training, some farmers may learn effective ways of growing rice according to their experience, which leads to an increased adoption rate among experienced farmers. Since these practices require more labor inputs and households may need to hire labor, asset holdings may affect adoption. Further, these practices have particularly significant impacts on rice production when water is available, so the adoption is also determined by the availability of water. When the plot is rented in, farmers may attempt to maximize the net returns to recover at least the land rental fee, which requires intensification such as the adoption of better cultivation practices.

In the regression analyses, a dependent variable takes unity if a new cultivation practice (bunding, leveling, timing of transplanting, or straight-row planting) was adopted between September 2008 and August 2009. Explanatory variables at the household level take the values at the beginning of September 2008 and those at plot level are measured in each respective cropping season. As explained above, the training variable is considered to be an endogenous variable. Thus, we apply the IV Probit model.

Table 11.8 shows the estimation results for the adoption of the four critically important cultivation practices taught in the JICA training. The probability of applying bunding and straight-row planting increases as the number of days for which households participated in the JICA training increases. The adoption rate of straight-row planting increases with lowland rice cultivation experience and decreases with age of household head. Better access to water, measured by the presence of a well, also increases the likelihood of using proper young seedlings and applying straight-row planting, indicating the complementarities between water availability and the improved production practices related with planting. When a plot is rented in, use of proper young seedlings is less likely to be implemented.

11.4.4 Effect of Training on Rice Yield

Whether participation in the training increases rice yields is examined in this subsection. The determinants of the yield in the cropping seasons of 2008–2009 are examined using cross-section data. The yield in the cropping season between September 2008 and August 2009 is assumed to be determined by household characteristics such as participation in training before September 2008, knowledge and application of recommended practices, rice cultivation experience, asset holdings, and household composition in September 2008, as well as plot characteristics such as water availability and the tenure security of the plot in the respective cropping seasons. Given that training participation, knowledge, and application of recommended practices are highly correlated, these variables are used in separate regressions. Although the training variable seems endogenous, the test of endogeneity shows that it is not endogenous. Thus, the yield function is estimated by OLS.

Table 11.8 Effect of training participation on new technology (cultivation practice) adoption (plot-level, 2SLS model) with district dummies

	Bunding	Leveling	Proper seedling age	Straight-row planting
	(1)	(2)	(3)	(4)
Training days participated (before Sep. 2008)	0.176 (2.08)*	0.069 (0.63)	0.132 (1.42)	0.362 (14.15)**
Year the household started cultivating lowland rice	0.001 (0.03)	-0.033 (1.10)	-0.009 (1.10)	-0.005 (1.75)*
Moved to this area after 2000 dummy	-0.208 (0.58)	0.049 (0.53)	-0.275 (0.34)	-0.344 (1.45)
Female-headed household dummy	-0.215 (0.31)	0.109 (0.13)	-0.656 (1.00)	
Land owned (ha)/number of adult family	0.221 (0.82)	0.108 (0.26)	0.108 (0.09)	0.161 (0.33)
Members (age 15–64)				
Initial assets (household, agricultural, livestock)	0.000 (0.24)	0.000 (0.50)	0.000 (1.26)	0.000 (0.98)
(USD)				
Head's age	-0.005 (0.42)	-0.024 (2.06)**	-0.024 (0.36)	-0.032 (1.61)
Head's years of schooling	-0.036 (0.94)	0.067 (0.52)	-0.017 (1.12)	-0.023 (0.97)
Water from canal	0.388 (1.02)	0.486 (0.81)	0.323 (0.81)	0.942 (0.91)
Well in the plot	0.549 (1.09)	0.480 (0.45)	0.878 (1.71)*	0.616 (1.88)*
Plot is rented in	0.403 (1.02)	0.870 (0.68)	-0.200 (1.98)**	-0.104 (0.54)
Size of plot (ha)	0.809 (1.06)	0.252 (0.44)	-0.798 (1.47)	-0.624 (1.12)
Plot is under customary tenure system	-0.064 (0.13)	0.507 (0.58)	-1.337 (0.58)	0.215 (0.38)
Bugiri		-0.342 (0.92)	0.200 (0.53)	
Pallisa	-0.305 (0.43)	-1.352 (1.36)	0.784 (1.36)	-0.427 (0.55)
Bukedea	-1.852 (2.31)**	-1.805 (2.81)***	-1.491 (1.23)	-2.379 (1.88)*
Constant	-0.698 (1.81)*	69.581 (1.14)	18.530 (1.14)	-1.316 (26.00)***
Wald Chi squared	47.3	60.0	60.5	208.4
Observations	253	253	253	253

* Significant at 10%; ** significant at 5%; *** significant at 1%

Table 11.9 shows the estimation results of the yield function in the cropping seasons of 2008–2009. As shown in column 1, participation in training increases rice yields: an additional training day increases the yield by 0.2 ton/ha. The correct

Table 11.9 Yield function (ton/ha), September 2008–August 2009 (OLS)

	(1)	(2)	(3)
JICA training days (before Sep. 2008) ^a	0.188 (4.47)***		
Answering quiz on leveling correctly = 1		0.096 (0.29)	
Answering quiz on seedling age correctly = 1		0.594 (1.85)*	
Bunds = 1			0.347 (0.62)
Leveling = 1			0.284 (0.76)
Proper seedling age = 1			−0.205 (0.63)
Straight-row planting = 1			0.734 (1.71)*
Head's age	−0.009 (0.68)	−0.013 (0.99)	−0.012 (0.88)
Head's years of schooling	−0.041 (1.01)	−0.031 (0.75)	−0.027 (0.64)
Female-headed household	−0.792 (1.03)	−0.818 (1.03)	−0.707 (0.88)
Year when household started cultivating lowland rice	0.257 (0.97)	0.249 (0.91)	0.236 (0.86)
Moved to this area after 2000 dummy	−0.036 (1.76)*	−0.046 (2.18)**	−0.042 (1.96)*
Land owned (ha)/number of adult family	0.615 (1.79)*	0.574 (1.61)	0.680 (1.88)*
Members (age 15–64)			
Initial assets (household, agricultural, livestock) (USD)	0.000 (1.12)	0.000 (1.09)	0.000 (1.23)
Water from canal	−0.309 (0.75)	−0.296 (0.69)	−0.366 (0.84)
Well in the plot	0.073 (0.11)	0.139 (0.21)	0.037 (0.06)
Plot is rented in	−0.459 (1.56)	−0.256 (0.84)	−0.384 (1.26)
Size of plot (ha)	−4.120 (5.39)***	−4.200 (5.30)***	−4.112 (5.13)**
Plot is under customary tenure system	0.102 (0.16)	0.134 (0.20)	0.091 (0.14)
Bugiri = 1	1.376 (3.89)***	1.913 (5.51)***	1.454 (3.16)**
Bukedea = 1	−0.472 (0.64)	−0.501 (0.65)	−0.432 (0.51)
Pallisa = 1	−0.571 (0.71)	−0.684 (0.81)	−0.739 (0.87)

(continued)

Table 11.9 (continued)

	(1)	(2)	(3)
Constant	76.314 (1.84)*	96.522 (2.26)**	87.350 (2.03)**
Observations	268	268	268
R-squared	0.36	0.32	0.32

* Significant at 10%; ** significant at 5%; *** significant at 1%

^aThis variable is tested to see whether it is an endogenous variable or not. It is found that it is not endogenous (by using Stata command “estat endogenous”; the test statistics cannot reject that they are exogenous variables). Therefore, we use OLS

knowledge about seedling age at transplantation has a positive effect on yield, suggesting an additional 0.6 ton/ha if farmers answered the quiz correctly. In terms of the actual application of improved practices, only straight-row planting has a significant impact on yield.

Unexpectedly, lowland rice cultivation experience does not increase the yield. Recent migrant household tends to have lower yield in all specifications. Households with larger per capita land owned tend to obtain higher yields. The other household characteristics do not have a significant impact on rice yield. Among plot characteristics, the size of the plot is the only variable that is significant: smaller plot size is associated with higher yields.

11.5 Conclusions

The most important finding of this study is that lowland rice yield can be extremely high in Uganda if basic production practices, such as bunding, leveling, and straight-row planting, are adopted along with the adoption of modern rice varieties and the use of simple irrigation systems, even if chemical fertilizer is not applied. Thus, there is no question that a lowland rice Green Revolution is possible in Eastern Uganda. Note that with the exception of the application of chemical fertilizer, the other important production practices are those commonly adopted in Asia, which suggests the high transferability of Asian rice farming technology to SSA. The major challenge is how to disseminate such a package of improved production practices to farmers.

According to our analysis, the intensity of training participation is the key to the adoption of the basic production practices. It was also found that training participation decreases as the distance from the demonstration plot increases. At the same time, however, nonparticipants in the training learn from those who participated. Further research is obviously needed to identify the most effective ways to disseminate new lowland production practices toward achieving major productivity gains in rice farming in Uganda and possibly in other areas in SSA.

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Part IV

Conclusion

Chapter 12

Market Access, Soil Fertility, and Income in East Africa

Takashi Yamano and Yoko Kijima

Abstract We identify the major factors affecting farm and nonfarm income by using panel data in Ethiopia, Kenya, and Uganda. We supplement the panel data with household-level soil fertility data and road distance data to the nearest urban center. The proportion of loose surface roads, instead of tarmac roads, has a clear negative association with crop income, livestock income, and per capita income in both Kenya and Uganda. We also find that soil fertility has a clear positive association with crop and livestock incomes in Kenya, but not in Uganda and Ethiopia. In Kenya, farmers produce not only cereal crops but also high-value crops and engage in dairy and other livestock production if the fertility of the soil is good.

Keywords Soil fertility • Market access • Poverty • Road infrastructure • East Africa

12.1 Introduction

In the previous case studies in this book, we have separately examined the causes and consequences of the adoption of various technologies and inputs, while controlling for market access and soil fertility. The main motivation of these case studies, as explained in Chap. 1, is that poverty is a consequence of the low endowment of assets and the low returns to such assets (Baulch 2000; Barrett 2005; Carter and Barrett 2006). The returns to the productive assets depend critically on

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technology and market access. For instance, improved seed varieties, combined with modern inputs, can increase crop yields dramatically, although the adoption of such technologies has been slow in Sub-Saharan Africa (SSA) compared to the rapid adoption of such technology in Asian countries during the Green Revolution period. Poor market access, in addition, increases input costs and reduces the selling prices of farm products and, hence, discourages farmers from participating in markets (de Janvry et al. 1991).

Market access and soil fertility are generally poor in African countries, as we discuss in Chap. 1. Rural roads are generally inadequate in terms of both coverage and quality, resulting in high transportation costs in Africa (Calderón and Servén 2008). The high transportation costs increase inorganic fertilizer prices, discourage farmers from producing perishable and high-value crops, and hence prevent farmers from increasing farm income. Regarding assets, land is one of the most important assets because most rural households rely heavily on farm income in Africa. The quality of the land, however, is considered to be deteriorating because of continuous cultivation with little external fertilizer application and inadequate land management (Smaling et al. 1997; Nkonya et al. 2004, 2008). In the previous chapters in this book, we have not examined how these factors are associated with the total income and welfare of the rural households.

In this chapter, therefore, we identify the associations of soil fertility, agricultural technology, and market access with incomes from three sources, i.e., crop, livestock, and nonfarm income in Ethiopia, Kenya, and Uganda. We use panel data in each of the three countries, interviewed twice in the period between 2003 and 2007, and estimate determinants of crop, livestock, and nonfarm incomes, in addition to total per capita income. The results indicate that the proportion of murram or dirt roads, instead of tarmac roads, has strong negative associations with crop and livestock incomes in Kenya and Uganda. This suggests that converting loose-surface roads to tarmac roads would increase the total per capita income in these two countries. In Ethiopia, we find an opposite result, which we believe is a result of program placements of a large-scale fertilizer credit program in the country.

The outline of this chapter is as follows: the next section discusses the conceptual framework on how soil fertility and market access affect rural poverty. Section 12.3 introduces the panel data used in this chapter. We explain the estimation models and how we measure the soil fertility and the distance to the nearest urban center in Sect. 12.4. The estimation results are provided in Sect. 12.5, which is followed by the conclusions in Sect. 12.6.

12.2 Conceptual Framework

Land degradation decreases the returns to land in a number of ways. We found that the soil carbon content, which is used as an index for soil fertility, has a strong positive association with maize yields in Kenya and Uganda (Chap. 7) and with banana yields in Uganda (Chap. 8). Also, the reduction in soil fertility decreases the application of

inorganic fertilizer (Chap. 7), presumably because it reduces the returns to external fertilizer (Marenja and Barrett 2009). Because of these impacts, we expect that farm households with poor soils have lower crop income than farm households with fertile soils, after controlling for the land size and other factors.

A possible means to compensate for the low crop income is to increase the income from other sources. There are two major non-crop income sources in the context of East Africa: livestock and nonfarm income. Livestock income includes income from sales of livestock and livestock products. In areas with low soil fertility and abundant land, the land could be used for grazing animals. In East Africa, grazing animals, especially local cattle, is popular in some remote regions, where rural households rely more on livestock income than in other regions. In areas with unfavorable agroecological conditions to agricultural production, both the crop and livestock activities may have low returns. Such low farm income is considered as a “push factor” that forces rural households into seeking nonfarm activities (Reardon et al. 2007; Hagglblade et al. 2007). In Asian countries, many farm households in unfavorable agricultural areas have escaped from poverty by increasing their nonfarm income over time (Otsuka and Yamano 2006; Otsuka et al. 2008).¹ In the three countries studied in this chapter, the nonfarm sectors are at different development stages. For instance, Matsumoto et al. (2006) show that the share of nonfarm income is 45% in Kenya, 30% in Uganda, and 5% in Ethiopia.

Regarding the relationship between market access and household welfare, there is a growing body of literature (Jacoby 2000; Minot 2007; Stifel and Minten 2008). Jacoby (2000), for instance, finds a negative relationship between the value of farmland and the community-level median traveling time to the nearest market center or agricultural cooperative in Nepal. A more recent study by Stifel and Minten (2008) finds that the crop yields of the three major crops in Madagascar, i.e., rice, maize, and cassava, are lower in isolated areas than in non-isolated areas. Although Jacoby (2000) and Stifel and Minten (2008) control for soil fertility in their analyses, their measurements of soil fertility are based on categorical classifications of soil fertility.

In this chapter, we extend these analyses in several ways. First, we use much more detailed soil fertility-related variables than in their studies. Second, both studies use the traveling time and cost variables at the community level to avoid measurement errors and endogeneity problems associated with the traveling time and costs. The endogeneity problem arises when households with better welfare or high agricultural productivity invest in better means of transportation. Our distance variable, however, is based on the geographical information system (GIS) coordinates of the sampled households. Thus, measurement errors do not depend on how the respondents estimate the traveling time, and the endogeneity problems, a point of concern in the previous studies, are not of concern because the GIS measured distance is not subject

¹For instance, over a 17-year period from 1987 to 2004 in Thailand, the increase in the nonfarm income share in the Northeast region, where the agricultural potential is low, was much higher than that in the Central region, where the agricultural potential is high (Cherdchuchai and Otsuka 2006). The authors conclude that the large decline in the poverty incidence in the Northeast region can be attributed primarily to the increased nonfarm income.

to change by household behavior. Last, while the previous studies examined impacts of markets on land values or crop yields, our analysis extends this to broader impacts on household income.

12.3 Data and Descriptive Analyses

12.3.1 Data

Among the three countries, Kenyan farmers have a higher income than Ugandan and Ethiopian households (Table 12.1). In Kenya, the average per capita income (all values are calculated using 2005/06 prices) was \$392 in 2004 and \$333 in 2007.² The average per capita income in Uganda is less than half of that in Kenya. Furthermore, the average per capita income in Ethiopia is much lower than in Uganda. As a result, the average per capita income in Ethiopia is less than one third of that in Kenya. Thus, although our sample households are poor by international standards, the level of the poverty differs considerably among our sample households across the three countries.

In Table 12.1, we also present the proportions of our sample households whose soil fertility data are available. Along with the first waves of the panel surveys in the three countries, we conducted soil sampling and measured a number of soil characteristics, as described in Chap. 1. We collected soil samples from the largest maize plot if the household cultivated maize and, if the household did not cultivate

Table 12.1 Size of sample households and per capita income

Region	Number of households	Per capita income (at 2005/06 price level)		% of households with soil data
		2003/04	2005/06	
	(A)	(B)	(C)	(D)
	Number	USD		%
Kenya	672	392.2	333.2	75.5
Uganda	894	132.4	169.3	63.1
Ethiopia	408	84.3	102.8	95.2

²We divide the total household income into crop income, livestock income, and nonfarm income. We calculate crop income by valuing all production and then subtracting the paid-out costs, which include the costs of seeds, fertilizer, hired labor, and oxen rental, from the total value production. In the case of livestock income, we included revenue from live sales plus production value of livestock products and then subtracted the paid-out costs, which include purchased feeds, expenditure on artificial insemination services, bull services, and animal health care services, out of the revenue that consists of sales of animals and livestock products, such as milk and eggs. To calculate the nonfarm income, we sum the monthly revenues for the past 12 months and subtract the monthly costs out of the total annual revenue and salaries from jobs that provide regular monthly salaries as well as wage earnings from seasonal jobs.

maize, we collected soils from the largest plot of non-maize cereal crops during the first cropping season of the first survey year. When the sampled households produced no cereal crops, we did not collect any soil samples. Moreover, some soil samples were lost or spoiled before being analyzed at the laboratory. As a result, the soil fertility data are only available for about 74% of samples households in the three countries studied in this chapter. The average soil carbon content is 2.4 in Kenya, 2.3 in Uganda, and 2.4 in Ethiopia. The Ethiopian samples have a smaller variation than the samples from the other two countries: the standard deviation is 1.1 in Ethiopia but is 1.5 in both Kenya and Uganda.

12.3.2 Soil Fertility and Income

To analyze the relationship between the soil fertility and the household income, we divide the sample households into four groups according to the soil carbon content in Table 12.2. Note that because we have the soil fertility data only for the subsample households, we only present the results among the subsample in this table. The table suggests that as soil fertility improves, per capita income increases in Kenya, but such a relationship cannot be found in Uganda. In Ethiopia, the relationship between the soil fertility and per capita income is opposite from what we find for Kenya. The unexpected relationship in Ethiopia is probably due to a large-scale fertilizer credit

Table 12.2 Household crop income and fertilizer use by the SOM quartile among soil subsample

	Soil carbon quartile				
	All	Q1 poor soil	Q2	Q3	Q4 good soil
	(A)	(B)	(C)	(D)	(E)
Kenya					
Per capita income ^a	367.0	300.2	341.4	382.2	447.5
% crop income ^a	35.8	34.2	35.5	34.2	39.4
% livestock income ^a	24.2	22.2	23.0	23.7	28.0
% nonfarm income ^a	41.5	46.3	43.2	42.8	33.5
Uganda					
Per capita income ^a	153.9	158.2	149.8	160.1	147.6
% crop income ^a	64.0	58.1	66.8	66.1	65.2
% livestock income ^a	12.7	11.0	12.6	14.0	13.3
% nonfarm income ^a	29.2	35.3	28.0	28.2	25.3
Ethiopia					
Per capita income ^a	93.7	125.4	100.7	76.1	79.4
% crop income ^a	52.5	57.8	50.9	51.5	50.8
% livestock income ^a	34.0	28.7	33.6	34.8	37.8
% nonfarm income ^a	11.6	10.7	11.4	13.6	10.5

Numbers are from the soil subsamples

^aCalculated from pooled data of 2003/04 and 2005/06; both values are adjusted to 2005/06 price level, USD

program, which distributes the fertilizer credit to farmers regardless of the market access and soil fertility as shown in Chap. 4 in this book. Regarding the composition of the income sources, we find a clear pattern in Kenya and Uganda. The share of crop and livestock incomes increases as the soil fertility improves, in contrast to the share of nonfarm income. The results are consistent with the “push factor” explanation that combination of poor soil fertility and low farm income pushed people into nonfarm activities to compensate for the low farm income.

The findings in Table 12.2 are informative, but the soil fertility could be correlated with other factors, especially with geographical factors, which may influence the welfare of the rural households. The level of soil fertility and the degree of market access, for instance, would be negatively correlated if cities and towns are formed around fertile land, as predicted by economic geography (Fujita et al. 2001). Thus, it is not clear if it is the low soil fertility or the poor market access that contributes to the low crop income. Moreover, the relationship between soil fertility and income may be bidirectional in that higher income may enable households to invest more in soils. To isolate the association of the soil fertility on the crop and other household incomes from other factors, and to discern causality from association, we rely on regression analyses.

12.4 Estimation Models and Variables

12.4.1 Estimation Models

We estimate the determinants of the crop, livestock, and nonfarm income with the Tobit model with the household random effects:

$$\ln(Y_{it}^K) = S_i \beta_S^K + M_i \beta_M^K + X_{it} \beta_X^K + e_{it}^K, \quad (12.1)$$

where Y_{it}^K is the log of the income from source K ; S_i is a set of soil characteristics of household i ; M_i is a set of market access variables of household i ; and X_{it} is a set of basic household characteristics of household i at time t . We have three income sources: crop income ($K=1$), livestock income ($K=2$), and nonfarm income ($K=3$). In addition, we also estimate the determinants per capita of total income ($K=4$). Because we have panel data at the household level and have some observations with zero income for some income sources, we estimate the model with the household random effects (RE) Tobit model. Because it is difficult to collect information on family labor inputs, we did not collect such information in our surveys. Thus, income is estimated by subtracting the paid-out costs from the value of production. Accordingly, the crop, livestock, and nonfarm incomes should be considered as the sum of the returns to the land, family labor, and unmeasured ability of the family members.

There are two major limitations with the estimation models. The first limitation is that we have at most one soil sample per household. Because of this limitation, we assume that the soil fertility is constant over time and across plots that belong

to each sample household in order to use all the observations in our panel data. Because the carbon content, our main soil fertility index, is stable over time as we mentioned earlier, this assumption may be acceptable regarding the time dimension. It could be, however, a strong assumption to apply across plots within households, especially when the plots are scattered. Titttonell et al. (2005), for instance, find that plots that are located close to homesteads are more fertile than remote plots by using soil samples of 60 households in Western Kenya. Thus, using the soil fertility data from one plot may generate biased estimators.

Despite these limitations, however, we have two reasons for maintaining our assumption. First, the same study, Titttonell et al. (2005), finds a relatively smaller variation in soil carbon across plots within households than in other soil nutrient variables, such as extractable P and K. The study finds a larger variation in soil carbon across communities than within households. Thus, regarding the soil carbon content, which we use as the main soil fertility indicator in this chapter, the potential bias problem may not be as serious as it would have been had we chosen other soil nutrient variables. Second, we use a large number of soil samples covering a wide geographical area in each country. Thus, there is significant variation in the soil carbon content across geographical areas, which helps to identify relationships between the soil fertility and the incomes.

The second major limitation of our estimation models is that, in addition to the soil fertility variables, the distance to roads and markets variables are also observed only once in our panel data. Moreover, these soil fertility and market access variables could be correlated with some omitted variables, such as farmers' ability. For instance, highly skilled or wealthy farmers might have invested in their soil fertility over time or have purchased land near roads in the past. If we had multiple observations, with sufficient variations of these variables over time, we could use models to control for unobserved household fixed effects and identify causal impacts. Without such multiple observations of the variables, we are unable to eliminate any potential biases created by omitted variables to identify causal impacts. Thus, in this study, we consider the results as observed associations between the independent variables and the outcome variables, instead of causal relationships between them.

12.4.2 Variables

For the soil variables, S_i , in the estimation models, we use the soil carbon content and its squared term, the pH and its squared term, and the ratio of sandy soil, as opposed to clay or loam soil.³ We use the squared terms of the soil carbon and pH because we may find nonlinear relationships between the outcome variables and the

³In this chapter, we do not present the results on the soil fertility-related variables, other than the SCC, to save space, although we include them in the regression models. The results on the other soil fertility-related variables are not significant for the most part.

soil variables. Since the soil variables are available for just the subsamples, we could estimate the models with the subsamples only. This method, however, may create selection biases because the subsamples with the soil fertility data are not selected randomly. To account for this, we replace all the soil-related variables with zero values and include an additional dummy variable for those households without soil data. To assure that our approach provides robust estimates, we estimate the same model for the entire sample and the subsample of households with soil data.

As mentioned earlier, to measure market access, M_i , we use the distance to the nearest urban center (above 100,000 inhabitants) on the three road types: dirt (or dry-weather only roads), loose-surface (all-weather roads), and tarmac road (all-weather roads, bound surface). Researchers at the International Livestock Research Institute, using a method employed by Baltenweck and Staal (2007), provided us the data in Kenya, Uganda, and Ethiopia. They used the GIS coordinates of the sampled households and the most recent digitized road maps of the three countries.

The household characteristics include human capital and asset variables. First, the human capital variables include the number of male and female adult members, 15 years old or older, in the household, and the maximum education levels of the male and female adult members. We use a dummy variable for female-headed households. Among household assets, we include the own land size in hectares and the total value of the household farm equipment, furniture, transportation means, communication devices, and other household assets; and the livestock value, which is the sum of the replacement values of cattle, goats, sheep, chickens, and pigs. Because the size and fertility of the land are separately included in the model, we do not include the value of land as a household asset.

12.5 Results

12.5.1 Kenya

According to the estimation results in Table 12.3, market access affects both crop and livestock incomes in Kenya. We find that per capita crop income and the per capita livestock income decline \$8.7 and \$5.4, respectively, among households that have such incomes, for every 10 km from the nearest urban center. In addition, both incomes decline further if the proportion of loose-surface roads, instead of tarmac roads, increases. If all the roads linking a household to an urban center were loose-surface roads, instead of tarmac roads, the crop income would decrease by \$42 and the livestock income would decrease by \$33. Regarding nonfarm income, we do not find any significant associations between market access and the nonfarm income. While good market access enables rural households to engage in nonfarm activities, poor market access pushes rural households to seek nonfarm income by migrating to urban centers. These opposing effects cancel each other out and make it difficult for us to find a clear impact toward one direction.

Table 12.3 Determinants of crop, livestock, and nonfarm income in Kenya (household random effects model, USD)

	Per capita crop income	Per capita livestock income	Per capita nonfarm income
	(A)	(B)	(C)
Market access to the nearest urban center			
Total distance (km)	-0.874 (2.60)***	-0.537 (1.77)*	0.648 (0.93)
Proportion of loose-surface road	-42.38 (2.12)**	-32.61 (1.80)*	-30.78 (0.74)
Proportion of dirt road	-6.723 (0.17)	-39.97 (1.09)	-16.05 (0.19)
Soil fertility			
Carbon	21.24 (2.10)**	19.89 (2.18)**	-18.56 (0.89)
Carbon squared	-1.041 (1.35)	-1.545 (2.24)**	1.044 (0.66)
Household and community characteristics			
Land size (ha)	18.50 (5.27)***	-3.050 (0.96)	0.217 (0.03)
Maximum education level of male adults	0.078 (0.08)	1.659 (1.93)*	3.714 (2.00)**
Maximum education level of female adults	0.154 (0.17)	-0.287 (0.34)	10.35 (5.62)***
Female headed household dummy	-11.97 (1.29)	-0.827 (0.10)	-8.836 (0.47)
Number of local cattle owned	0.072 (0.04)	9.211 (5.75)***	5.422 (1.57)
Number of improved cattle owned	5.404 (3.40)***	21.01 (14.3)***	7.063 (2.27)**
Constant	-18.45 (0.06)	212.7 (0.83)	-324.9 (0.55)

pH, pH squared, numbers of male and female household members, numbers of sheep and goats, and a year dummy for the second round of the surveys are included but not presented in the table

* Significant at 10%, ** significant at 5%, *** significant at 1%

Soil fertility, measured in the carbon content, has a positive and significant impact on both crop and livestock incomes, while it does not have any significant impacts on nonfarm income. In the crop income regression, the positive effect suggests that good soil enables farmers to choose crops that have high returns in Kenya, and to obtain high yields from crops, as shown by Chap. 7. Because the squared term of the carbon has a negative coefficient on both crop and livestock incomes, the relationship between soil fertility and each income source has a peak. A quick calculation shows that the crop income model has a peak where the soil carbon content is about 10. Since the carbon content value at the 90th percentile is 9.2 in Kenya, we can safely state that the crop income increases as the carbon content

increases within much of the observable range of the data. The peak carbon content for livestock income is at 6.6 and there exist some households whose soil fertility is beyond 6.6. It may be that those who have fertile soils focus on crop production, instead of livestock production, because their crop production has large returns due to the high soil fertility.

Regarding household characteristics, we find that the crop income increases as the size of land owned increases in Kenya. This is what is expected because the dependent variable is the “total” crop income per capita. When we estimate the same model for the crop income per ha, we find that the land size has a negative relationship with the crop income per ha. In fact, we find the same pattern, i.e., a positive coefficient on the total crop income and a negative coefficient on the crop income per ha, in all three countries. This suggests that smaller farms have a high productivity per land in these countries. Although some farmers still have large lands, which are not cultivated intensively in these countries, the number of such farmers is decreasing. Compared with such farmers, small landholders intensify their production by using relatively abundant family labor. This could be why we find higher productivity among small landholders.

Next, we find that the number of improved cattle has a positive coefficient on all income sources. Depending on the specific dependent variable, the results may be more indicative of an association rather than a causal relationship. For instance, the positive coefficient of this variable in the nonfarm income regression model suggests that the number of improved cattle is a proxy for household wealth, which is positively correlated with the nonfarm income. On the crop income, however, we believe that the positive coefficient of the number of improved cattle captures, at least partly, a complementary effect in dairy–crop integration where farmers use cattle manure, obtained from improved cattle, as organic fertilizer, as studied in Chap. 8 in this book. This may be supported by the absence of the significant effect of local cattle ownership on crop income, as improved cattle kept in stalls provide more manure, which is also more easily collected as compared to local cattle.

In Kenya, both men’s and women’s education have positive coefficients on nonfarm income, and the magnitude of the women’s coefficient is larger than the men’s. Previous studies on nonfarm income show that education is an important requirement to be engaged in such activities in both Asia and Africa (Otsuka et al. 2008; Matsumoto et al. 2006). We do not find significant coefficients of men’s and women’s education levels on the crop income. This suggests that there are few agricultural technologies that require high levels of education.

12.5.2 *Uganda*

Contrary to what we find in Kenya, crop income is higher in remote areas in Uganda (Table 12.4). This is understandable in Uganda where high-value crops such as banana and coffee are produced in highland or mountainous areas, which happen to be located in the extreme east, west, and southwest of the country. Holding the distance to urban centers constant, however, we find that the crop

Table 12.4 Determinants of crop, livestock, and nonfarm income in Uganda (household random effects model, USD)

	Per capita crop income (A)	Per capita livestock income (B)	Per capita nonfarm income (C)
Market access to the nearest urban center			
Total distance (km)	0.537 (1.79)*	-0.147 (1.40)	-0.213 (0.77)
Proportion of loose-surface road	-96.54 (2.55)**	-4.635 (0.34)	12.24 (0.35)
Proportion of dirt road	-31.18 (1.43)	0.219 (0.03)	-0.941 (0.05)
Soil fertility			
Carbon	10.190 (1.20)	0.663 (0.21)	-7.771 (0.99)
Carbon squared	-1.334 (1.41)	-0.343 (0.92)	0.710 (0.83)
Household and community characteristics			
Land size (ha)	7.200 (2.41)**	0.652 (0.69)	-3.347 (1.28)
Maximum education level of male adults	3.530 (1.85)*	0.032 (0.05)	6.741 (3.96)***
Maximum education level of female adults	-1.935 (0.92)	1.600 (2.26)**	3.924 (2.12)**
Female-headed household dummy	-12.88 (0.65)	-10.79 (1.53)	-46.44 (2.49)**
Number of local cattle owned	1.263 (1.19)	6.996 (21.70)***	-1.854 (1.94)*
Number of improved cattle owned	2.077 (0.68)	8.450 (9.10)***	1.169 (0.46)
Constant	-674.846 (0.93)	-5.534 (0.02)	-23.56 (0.03)

pH, pH squared, number of male and female household members, number of sheep and goats, and a year dummy for the second round of the surveys are included but not presented in the table

* Significant at 10%, ** significant at 5%, *** significant at 1%

income decreases significantly if the proportion of loose-surface roads is higher instead of tarmac roads. If all the roads were loose-surface roads, instead of tarmac roads, the crop income per capita would decrease by \$97. Because banana can be spoiled easily on bumpy roads when they are transported on trucks, the proportion of loose-surface roads may have a negative impact on the price of banana. Thus, there is a potential gain that could be obtained by upgrading loose-surface roads to tarmac roads. On dirt roads, we do not find a significant coefficient, which may suggest that such roads are not used for transporting high-value crops.

In Uganda, we find that soil fertility does not have any significant coefficients on all three income sources. The soil samples are taken from plots where cereal

crops are cultivated. As we mentioned earlier, banana is an important staple crop, which tends to have high returns. Thus, the soil fertility data may not represent soil fertility where banana is cultivated, and this could be why we do not find significant coefficients for the soil fertility on the crop income.

Both the numbers of local and improved cattle increase the livestock income, suggesting the importance of the ownership of cattle in this country. Compared with the finding for Kenya, the size of the estimated coefficient of the number of improved cattle in Uganda is smaller. In Kenya, dairy farmers who own improved cattle are very successful in producing and selling large amounts of milk in a liberalized milk market, as shown in Chap. 5. In contrast, the Ugandan dairy sector is not as advanced as in Kenya. The smaller coefficient on the improved cattle on the livestock income in Uganda than in Kenya suggests a need for improvements in the dairy sector in Uganda. Another difference is that in Uganda, the number of improved cattle does not have a significant coefficient on the crop income, as we find in Kenya. This also suggests that the dairy–crop production system is not as well integrated as in Kenya, although there are some farmers who integrate them in Uganda, as shown in Chap. 8.

12.5.3 Ethiopia

In Ethiopia, crop income does not have clear relationships with either market access or soil fertility (Table 12.5). As Chap. 4 in this book shows, fertilizer credit is provided to farmers regardless of their agricultural potential, including market access and carbon content. Because the fertilizer credit program is a large-scale operation in Ethiopia, its politically determined distribution pattern may help explain why we do not find any relationships between the crop income and both the market access and the soil fertility in the country.

The number of local and improved cattle have positive coefficients on the livestock income. Moreover, as in Kenya, the improved cattle have a larger impact on livestock income than the local cattle, which suggests that the introduction of improved cattle is an important innovation. The number of improved cattle also has a positive coefficient on the crop income. Thus, in Ethiopia, we find evidence that the dairy–crop integration has a complementary effect. Because the soil fertility is very poor in some areas of Ethiopia, organic manure taken from improved cattle, which are easy to collect manure from, may be very effective in improving soil fertility in the country.

12.5.4 Total Per Capita Income

Regarding the market access, we find that the proportion of loose-surface roads has large negative relationships with per capita income in Kenya and Uganda. These results indicate that farmers' income increases if the loose-surface roads are converted to tarmac roads. In Ethiopia, the proportion of the loose-surface roads

Table 12.5 Determinants of crop, livestock, and nonfarm income in Ethiopia (household random effects model, USD)

	Per capita crop income	Per capita livestock income	Per capita nonfarm income
	(A)	(B)	(C)
Market access to the nearest urban center			
Total distance (km)	-0.016 (0.19)	0.041 (0.72)	-0.223 (0.78)
Proportion of loose-surface road	23.610 (1.60)	-6.538 (0.61)	84.21 (0.12)
Proportion of dirt road	n.a.	n.a.	n.a.
Soil fertility			
Carbon	-13.654 (0.96)	3.201 (0.32)	-37.81 (1.47)
Carbon squared	2.188 (1.11)	-0.020 (0.01)	5.352 (1.53)
Household and community characteristics			
Land size (ha)	7.645 (3.81)**	0.158 (0.11)	2.855 (0.87)
Maximum education level of male adults	-0.638 (1.86)*	0.074 (0.31)	0.667 (1.24)
Maximum education level of female adults	-0.352 (0.80)	0.462 (1.48)	0.898 (1.32)
Female-headed household dummy	-0.212 (0.03)	-5.940 (1.03)	33.07 (2.41)*
Number of local cattle owned	-1.523 (1.88)	5.527 (9.53)**	1.208 (0.85)
Number of improved cattle owned	16.40 (6.47)**	18.82 (10.43)**	3.010 (0.71)
Constant	44.98 (0.13)	33.75 (0.14)	-1,683 (2.39)*

* Significant at 10%, ** significant at 5%

has a positive correlation with per capita income. This is most likely due to the positive correlation between the proportion of loose-surface roads and the crop income, found in Table 12.3. Because farmers have a very low level of nonfarm income in Ethiopia, the results on per capita income are similar to the ones for the crop income per capita.

We find no significant relationships between soil fertility and per capita income (Table 12.6). An earlier study by Yamano and Kijima (2010), who use the same Ugandan data set used in this chapter, suggests that households with poor soil fertility tend to earn more nonfarm income than those households with better soils. As a result, they find that the total income has no relationship with the soil fertility. We think that the same explanation can be applied to the other two countries. Especially in Kenya, households have a high level of nonfarm income (Matsumoto et al. 2006).

Table 12.6 Determinants of per capita income (household random effects model, USD)

	Kenya	Uganda	Ethiopia
	(A)	(B)	(C)
Market access to the nearest urban center			
Total distance (km)	-0.765 (0.92)	0.364 (1.02)	-0.082 (0.73)
Proportion of loose-surface road	-105.1 (2.13)**	-99.03 (2.17)**	51.54 (2.47)**
Proportion of dirt road	-67.87 (0.68)	-51.04 (1.96)**	n.a.
Soil fertility			
Carbon	22.24 (0.89)	7.810 (0.76)	-24.43 (1.16)
Carbon squared	-1.650 (0.87)	-1.246 (1.10)	3.936 (1.35)
Household and community characteristics			
Land size (ha)			
	15.51	6.834	10.88
Maximum education level of male adults	(1.83)*** 5.456	(1.94)* 7.892	(3.77)*** -0.046
Maximum education level of female adults	(2.42)*** 9.535	(3.47)*** 2.184	(0.10) 0.186
Female-headed household dummy	(4.29)*** -22.85	(0.87) -28.47	(0.30) 8.372
Number of local cattle owned	(1.01) 14.03	(1.21) 7.298	(0.71) 4.065
Number of improved cattle owned	(3.33)*** 32.38	(5.87)*** 12.69	(3.48)*** 34.90
Constant	(8.45)*** 139.2	(3.59)*** -36.14	(9.60)*** -309.0
Market access to the nearest urban center	(0.20)	(0.04)	(0.60)

* Significant at 10%, ** significant at 5%, *** significant at 1%

Thus, it is possible for them to compensate the low farm income, due to poor soils, with the nonfarm income. This also indicates that households with poor soil fertility do not find it worthwhile to invest in enriching their soils and prefer instead to seek returns through other means.

Men's education level has a strong positive correlation with per capita income both in Kenya and Uganda. This suggests that men are engaged more in nonfarm activities than in farm activities in these countries, as we did not find similar results on the crop income in the previous tables. In Kenya, we also find a positive coefficient on women's education, and the size of the positive coefficient is larger than that on men's education. This suggests the importance of improving women's education levels for poverty reduction in Kenya. Finally, we find that both local and improved cattle ownership have positive relationships with per capita income. Although the causality is not clear, the results indicate the importance of cattle ownership in the three countries.

12.6 Conclusion

In this chapter, we explored income levels and their composition in three East African countries and then analyzed the degree to which they are related to soil fertility, agricultural technology, and market access. First, a key point is that agriculture is still vitally important to overall household income throughout the region. This is supported by the high proportion of income from crop and livestock and also the importance of land size to overall household income. The analytical results indicate that the proportion of the loose-surface roads, instead of tarmac roads, has a clear negative association with crop income, livestock income, and per capita income in both Kenya and Uganda, while controlling for the total distance to the nearest urban center. Transportation costs per unit distance on loose-surface roads are higher than those on tarmac roads in general. During rainy seasons especially, surface roads can be impassable, which increases transportation costs significantly and leads to the spoilage of relatively perishable crops such as banana. The results, therefore, indicate the importance of road quality, in addition to the distance to urban centers.

We find that soil fertility has a clear association with crop and livestock incomes in Kenya, but not in Uganda and Ethiopia. In Kenya, farmers produce not only cereal crops but also produce high-value crops and engage in dairy and other livestock production if the fertility of the soil is good. Good soil fertility also increases land productivity as shown in the case of maize in Chap. 7 of this book. In Uganda and Ethiopia, soil fertility is lower than in Kenya on average, but the difference is small, and there are many farmers with very good soil in both countries. What is necessary in these countries are technologies and crops that can take advantage of the good soil and market opportunities. Without such technologies and market opportunities, investments in soil fertility will have only low returns.

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Chapter 13

Conclusion: Toward the Transformation of Agriculture in East Africa

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Abstract The eleven case study chapters are used to evaluate the three main hypotheses of the book which are related to the importance of markets, technological innovations, and soil fertility. We find that markets for fertilizer and some agricultural products are functioning well and that farmers are responding to changes in the markets by changing crop choice, input use, and agricultural technologies. We also find that there are ample examples of technological innovations that are productive and profitable on farms and suitable for wider scaling up in the region. In order to realize this potential, however, improving soil fertility is found to be a prerequisite. There are examples in East Africa where these three critical factors have been realized and have led to measureable success, especially in the intensive dairy-cropping systems. The policy implications for expanding these successes in Africa are stated at the end of the chapter.

Keywords Agricultural policy • New technologies • Market development • Soil fertility management

13.1 Introduction

Why has agriculture failed to develop in Sub-Saharan Africa (SSA), in contrast to Asia where the Green Revolution has taken place and contributed to the transformation of agriculture from a stagnant to a dynamically growing sector? What are the main barriers to growth in African agriculture? More specifically, is the malfunctioning of

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markets for agricultural products and inputs a major hindrance to the adoption of new technologies, which increase both the supply of agricultural products and the demand for purchased inputs? What are the effects of deteriorating soil fertility on the profitability of applying fertilizer and adopting new technologies? Are there any signs of promising technological development in African agriculture? These are the issues we attempted to address in this study.

We believe that the economic forces identified by the theory of induced innovation advanced by Hayami and Ruttan (1985) should work not only in Asia but also in Africa. In our interpretation, their theory simply argues that the adversity created by the increasing scarcity of critical inputs, such as land, “necessitates” efforts to save such inputs (i.e. to instead intensify the use of other inputs). It is surprising if farmers, researchers, and policymakers do not attempt to save land in the production process or to increase land productivity when land becomes scarcer and, hence, the relative price of land increases.

In contemporary SSA, land has been becoming scarce and there have been many corresponding attempts to save land (e.g., Otsuka and Place 2001). Indeed, the increasing application of inorganic fertilizer in Kenya, discussed in Chap. 3; the introduction of improved cows that are kept in stalls, and fed by fodder grown in the field and purchased feeding concentrates, reported in Chap. 6; the use of organic fertilizer discussed in Chap. 9; and the introduction of new rice varieties analyzed in Chaps. 10 and 11 are all excellent examples of new attempts to save land. Moreover, the decreasing communal grazing area due to population pressure increases the number of improved cattle, which are several times more productive than traditional local cows in milk production and the production of manure (Chap. 9). There is, therefore, no doubt that the induced innovation theory is relevant for East Africa.

Moreover, these technologies are found to be highly promising. For example, the yield of lowland rice in Uganda is found to be comparable with or even higher than the average lowland rice yield in Asia, if proper production practices are adopted (Chap. 11). The yield of upland NERICA rice in Uganda is no less impressive (Chap. 10); the average NERICA yield is twice to three times as high as the average upland rice yield in SSA. Although not as impressive as rice yields, the yield of maize in Kenya is reasonably high (e.g., well above 2 ton/ha), if hybrid maize is adopted together with the application of inorganic fertilizer as well as organic fertilizer supplied by dairy cows (Chap. 8). Thus, the basic premise of this study that a number of potentially productive agricultural technologies are available in East Africa is unequivocally supported by the empirical evidence, even though there is further room for technology improvement.

The availability of promising new technologies is not enough, however. Unless markets assist the sale of increased products at reasonably high prices and the purchase of inputs at reasonably low prices, new technologies will not be adopted or even if adopted, their profitability will be low. Particularly important are the need to avoid the collapse of output prices in local markets when local production increases appreciably and to assure the availability of inorganic fertilizer at affordable prices, as it is highly complementary to high-yielding crop varieties. According to our analyses of maize markets in Chap. 2, inorganic fertilizer markets in Chap. 3,

milk markets in Chap. 5, and banana markets in Chap. 7, there is no evidence to indicate that agricultural markets do not function well in East Africa, even though transportation costs are high due to poor road infrastructure.

All these findings point to the emerging favorable trend of agricultural development in East Africa. Declining soil fertility, however, may impede such development to the extent that poor soil fertility decreases the return to the application of inorganic fertilizer. In this concluding chapter, we summarize the major findings of this book in light of the three hypotheses postulated in Chap. 1, with a view to designing strategies to transform “traditional agriculture” to “modern dynamic agriculture,” in the sense of Schultz (1964), in East Africa.

13.2 Do Markets Function?

Although ideally we would like to test directly whether markets work competitively, it is an analytically formidable task to identify the competitiveness of the market. In this book, we examined whether the transportation cost, which is measured by the travelling time and distance between farms and nearby local markets and between local markets and national market centers as well as the type of road, is a major determinant of market prices, and whether household and community characteristics affect market prices. If local markets are competitive and sufficiently integrated over wide areas, it is the transportation cost alone that determines the local prices relative to the urban market price, without any impacts of household and community characteristics, including agro-climatic factors, on local market prices.

Given this criterion, our analyses overwhelmingly support the hypothesis that markets function well. According to Chap. 2, the farm-market maize price spread is determined primarily by the travelling time between farms and the nearest major market center, particularly in Kenya. Chapter 3 provides evidence that the market price of inorganic fertilizer is determined primarily by market access in Kenya, where the fertilizer market has been liberalized, whereas markets are highly distorted by government interventions in Ethiopia. Also in Kenya, Chap. 5 indicates that newly emerging private traders play an important role in milk marketing, which has successfully replaced marketing by the traditional milk marketing cooperatives, after some years of market liberalization. As a result, the chapter shows that the farm-market price spread has reduced in the milk market over time. Furthermore, Chap. 6 shows that the availability of formal milk marketing outlets, which has been improved since the market liberalization, encourages farmers to adopt improved cows and feed concentrates. Thus, functioning markets help farmers to adopt new technologies.

Markets, however, do not function well if the government intervenes in the markets. Chapter 4 exemplifies such a case by analyzing the fertilizer markets in Ethiopia where fertilizer subsidies have been provided. Furthermore, it is found that the use of credit and the resultant increases in fertilizer application did not have significant effects on maize and wheat yields, even though it had impacts on the yield of teff, which is low yielding but commands a high market price. The absence of the yield effect is most likely attributable to the fact that high-yielding varieties

(HYV) were seldom adopted by Ethiopian farmers. This case clearly illustrates that subsidizing fertilizer use does not lead to increased crop yields unless it is accompanied by the dissemination of fertilizer-responsive, high-yielding crop varieties.

In sum, the chapters in Part II support Hypothesis 1, which states that “although transportation costs remain high, agricultural product and fertilizer markets are functioning in East Africa unless governments intervene in the market.”

13.3 Do Farmers Respond?

Even if markets function, if farmers do not respond to market signals, efficient resource allocation cannot be achieved. As Schultz (1964) predicted several decades ago, “farmers are poor but rational” in developing countries. As is shown in Chap. 3, farmers reduce the use of inorganic fertilizer in areas where its price is high in Kenya. Such a tendency is not observed in Ethiopia, where the fertilizer market is heavily distorted, and in Uganda, where the majority of farmers neither apply inorganic fertilizer nor use purchased hybrid seeds. According to the estimation of the marginal products of inorganic fertilizer in maize production in comparison with the ratio of fertilizer to maize price in Chap. 7, it is rational for farmers in Uganda not to apply any inorganic fertilizer due, importantly, to the high relative fertilizer price. Furthermore, maize farmers in Kenya roughly equalized the marginal product with the relative price and responded to changing relative prices by adjusting the amount of application of inorganic fertilizer. In Ethiopia, we have clear evidence that farmers do respond to the provision of fertilizer credit by applying more inorganic fertilizer. Thus, the low application of inorganic fertilizer in East Africa can be explained by the high relative price of inorganic fertilizer, the low adoption of fertilizer-responsive crop varieties, and the unavailability of cheap credit, to a significant extent.

The development of markets seems to have affected the adoption of new technology. Chapter 6 provides an interesting finding that market access, measured by travelling time and distance from farms to markets, affects the adoption of new dairy technologies, viz., dairy cows, cultivation of fodder, and the use of feeding concentrates. The reduction in marketing cost, due to the mobile phone coverage in Uganda, stimulates the production of bananas to sell to the markets, particularly in remote areas, as reported in Chap. 7. Also in Uganda, market-oriented banana producers apply manure to banana fields primarily by introducing improved cows, which, in turn, leads to increased banana yields (Chap. 9). This dairy–crop integration is exceedingly important not only for increasing crop yields in the short run but also for enhancing the sustainability of farming, as the manure application contributes to the improvement of soil quality.

Although not stated explicitly, the market ought to play an important role in the dissemination of upland NERICA rice and lowland high-yielding rice in Uganda, simply because rice is primarily a commercial crop in this country. Furthermore, a recent study by Kijima et al. (2011) shows that the distance to the nearest rice miller

from the famers' residences declined appreciably over time due to the mushrooming of rice millers, which stimulated the adoption of NERICA rice. Thus, the development of rice milling markets, which would have been stimulated by increasing rice production, leads to the expansion of NERICA rice production in countries where upland rice had not been cultivated in wide areas. The analysis of the crop income in Chap. 12 indicates that the distance and poor road conditions decrease crop income in Kenya, not only because the unfavorable market access increases input prices and decreases output prices but also because the cultivation of high-value crops, such as vegetables, becomes unprofitable in remote areas not connected by tarmac road.

Thus, we have enough evidence to support Hypothesis 2, which states that "farmers respond to improved market conditions by applying more fertilizer, adopting more productive cows, and producing more profitable crops."

13.4 Does Poor Soil Fertility Impede Development?

A unique feature of this study is the use of soil fertility data. As was pointed out in various contexts, however, the soil samples were collected only from one maize or other cereal crop field once due to the high costs of soil collection and analysis. Possibly due to this limitation, we failed to detect the significant impact of soil fertility at the household-level analysis in a number of cases. Nonetheless, Chap. 3 finds that, in Kenya, farmers apply more inorganic fertilizer on better soils, which have a high rate of carbon content. Furthermore, Chap. 8 finds that the soil carbon content has a strong impact on maize yield. The elasticity evaluated at the means is about 0.32 for the purchased HYV maize, while it is about 0.57 for the local/recycled HYV maize. We found in Chap. 9, that lower soil fertility is associated with larger application of organic fertilizer in the western region of Uganda, where the dairy-banana integrated farming system is widely practiced. It appears that organic fertilizer is applied to restore the fertility of depleted soil. Such an interpretation is consistent with the finding that both the soil fertility and the application of organic fertilizer are important determinants of the banana yield.

We found in Chap. 10 that the yield of NERICA rice in Uganda is higher in the fields in which tobacco was grown previously because inorganic fertilizer was amply applied so that some soil nutrients still remained when NERICA was grown, and in the fields in which leguminous crops with the ability to fix nitrogen were previously grown. Although inorganic fertilizer is seldom applied, NERICA rice seems to be responsive to the application of inorganic fertilizer as well as to soil fertility. In Uganda, lowland rice is generally grown in the valley bottom where fertile soil accumulates. The rice yield per ha exceeds 4 tons without fertilizer being applied in Bugiri in Uganda (Chap. 11), which is roughly the average lowland rice yield in Asia where inorganic fertilizer is amply applied. Although we did not assess the soil fertility in the analysis of lowland rice, it seems obvious that the soil fertility does matter in the high-yield performance of lowland rice in Uganda.

According to the analysis of the determinants of income in Chap. 12, higher soil fertility is associated with higher crop and livestock incomes per capita in Kenya, which suggests that a highly productive integrated farming system is practiced in which stall-fed improved dairy cows produce milk and supply manure to crop fields. In contrast, the absence of the significant effects of soil fertility in the regression analyses of per capita crop and livestock incomes in Uganda and Ethiopia indicates that such a farming system is not widely adopted in these countries, even though the integrated dairy–banana farming system is observed in the western region of Uganda (Chap. 9).

To sum up, we have evidence to support Hypothesis 3, which states that “poor soil fertility impedes the adoption of fertilizer responsive crop varieties and the use of inorganic fertilizer, even though it may increase the use of organic fertilizer to restore the soil fertility.”

13.5 What Must Be Done?

According to the income analysis conducted in Chap. 12, education is a critically important determinant of total per capita income because it is positively and significantly related with per capita nonfarm income. Based on this observation, one may be tempted to conclude that in order to reduce rural poverty what is important is investment in the schooling of children as well as the creation of job opportunities in the nonfarm sector. We do not agree with such a narrow interpretation, however. According to a recent study of rural poverty and income dynamics in Asia by Otsuka et al. (2009), it was the Green Revolution that stimulated the investment in the schooling of children by increasing the income of farm households in many Asian countries. Subsequently, the educated children found lucrative nonfarm jobs and thereby contributed to the poverty reduction. Indeed, it is inconceivable that the parents of rural families in SSA actively invest in the schooling of their children when their incomes remain low due to stagnant agriculture. We believe that as in Asia, SSA needs major breakthroughs in agricultural production for poverty reduction and overall economic development.

What policy implications for agricultural development in SSA can we draw from this series of studies. Broadly, there are three implications concerning (1) markets, (2) innovations, and (3) soil. First, in order to support the markets, the government should invest in road and communication infrastructures. As we have seen, the markets for agricultural products and inputs seem to function well in Kenya and Uganda. Yet, marketing costs seem high primarily because of the poor transportation infrastructure. Thus, investments in such infrastructure are badly needed. Another possible policy intervention is the certification system of improved seeds, which is missing particularly in Uganda. In Ethiopia, where the interventions in the market by the government are pervasive, the policy to promote the participation of private actors in free market transactions should be pursued. We anticipate that the further improvement of marketing systems will help farmers adopt yield-increasing technologies, which require the use of modern, purchased inputs.

Second, in order to realize agricultural innovations, the government must invest in crop and livestock research and agricultural extension systems. For maize, we believe that both research and extension systems must be strengthened judging from the fact that maize yields are deplorably low even in the highlands of Kenya compared with Southern Asia, where the maize productivity is lagging behind other Asian countries, and Latin America. According to FAOSTAT, the average maize yield is 2.4 ton/ha in Southern Asia and 3.9 ton/ha in Latin America during the 5-year period of 2003–2008. Chapter 8 shows that the average maize yield is 2.0 ton/ha in Kenya and 1.7 ton/ha in Uganda. Therefore, the yield potential of maize must be enhanced not only in Kenya but also in Uganda and Ethiopia, where the adoption rates of improved maize seeds are low due, presumably, to the lack of suitable improved seeds. In our observation, Ugandan farmers generally do not know how productive hybrid maize is if it is combined with the application of inorganic fertilizer, because they have never tried to adopt hybrid maize and inorganic fertilizer. Extension systems on maize technology are also weak. For banana, we would like to point out that the improved plants are not widely available in Uganda, even though banana is a main staple food. For improved dairy cows, research on their improvement has been neglected in the countries, despite the fact that the introduction of dairy cows is a major agricultural innovation in East Africa, which has significantly contributed to the increased application of manure, increased crop yields, and increased livestock and crop incomes. We must also mention that extending knowledge on how to make compost is highly recommended, as compost is more effective than manure in increasing crop yields. Regarding rice, a major constraint on innovations is the weak extension system. As was stressed before, both upland NERICA rice and lowland rice yields are potentially very high by international standards. What is missing is a strong extension system. Indeed, there are very few extension workers in Uganda who are knowledgeable about rice farming. It must also be recognized that compared with upland farming, lowland rice farming is technically more complicated, requiring careful land preparation including bunding and leveling, nursery bed preparation, transplanting, and water management. Lowland rice farmers in SSA must learn these production practices from the extension system in order to realize the huge yield potential in this region.

Third, in order to improve the soil fertility and increase the sustainability of agriculture in East Africa, both the governments and international communities, including the Consultative Group for International Agricultural Research, should invest in the establishment of appropriate mixed dairy–crop farming systems consisting of the use of further improved dairy cows, the “optimum” use of both inorganic and organic fertilizers as well as feeding concentrates, the adoption of suitable improved high-yielding seeds, and the pertinent crop rotation systems including the cultivation of grains, leguminous crops, and fodder crops for dairy cows. It should be noted that the Asian Green Revolution was led by the introduction of high-yielding lowland rice varieties and that lowland rice cultivation systems are highly sustainable if adequate amounts of inorganic fertilizer are applied because water carries a variety of micronutrients and because nitrogen-fixing micro plants are grown in paddy fields. In SSA, the maintenance of the soil fertility of

upland fields is a prerequisite for a major Green Revolution. In our view, the well-integrated mixed dairy–crop farming system has been clearly demonstrated to be essential for a Green Revolution in many areas of SSA in the foreseeable future. The move toward such a farming system is taking place in various parts of East Africa, even though systematic support for such a move is lacking. Other places in SSA, which similarly exhibit low fertilizer use, are also likely to require integrated systems to increase organic nutrients to build up soil fertility.

Finally, we would like to emphasize that the Green Revolution is *not* automatically induced by increasing resource scarcity, as has been emphasized by Ruttan and Hayami in the new volume edited by Otsuka and Runge (2011). Scientists and policy makers must carefully design it to be achieved.

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